DIVISION OF BIOLOGICAL RESEARCH
COLLECTED REPRINTS

1961

VOLUME I

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

U.S.F.W.S.
SK361
A2C4
1961
U.S.F.W.S.
DIV. OF BIOL.
RES.
COLLECTED
REPRINTS
V. 1

DATE ISSUED TO

U.S.F.W.S.
SK361
A2C4
1961
V. 1

U.S.F.W.S. DIVISION
OF BIOLOGICAL RESEARCH
COLLECTED REPRINTS.

LIBRARY
BUREAU OF COMMERCIAL FISHERIES
U. S. FISH AND WILDLIFE SERVICE
P. O. BOX 3830
HONOLULU 12, HAWAII

Fish and Wildlife Service

LIBRARY
APR 8 1963
FISH & WILDLIFE SERVICE

Digitized by the Internet Archive
in 2025

https://archive.org/details/collected-reprints-division-of-biological-research_1961_1

UNITED STATES DEPARTMENT OF THE INTERIOR, Stewart L. Udall, *Secretary*
FISH AND WILDLIFE SERVICE, Clarence F. Pautzke, *Commissioner*
BUREAU OF COMMERCIAL FISHERIES, Donald L. McKernan, *Director*

DIVISION OF BIOLOGICAL RESEARCH

COLLECTED REPRINTS

U. S. F. W. S.
SK361
A2C4
1961
3068 63
V.1

1961

This volume contains reprints from the Division of Biological Research which appeared during 1961 in publications other than those of the Fish and Wildlife Service.

MARCH 3, 1849

7898

Washington, D. C.
1962

DIVISION OF BIOLOGICAL RESEARCH REPRINTS
APPEARING IN OTHER THAN FISH AND WILDLIFE SERVICE PUBLICATIONS

1961

Author Index of Collected Reprints

1. AHLSTROM, ELBERT H.
   Distribution and relative abundance of rockfish (Sebastodes spp.) larvae off California and Baja California. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procéedings-Verbaux des Reunion, vol. 150, p. 169-176, September 1961.
   L.J.

2. APPLEGATE, VERNON C., JOHN H. HOWELL, JAMES W. MOFFETT, B. G. H. JOHNSON, AND MANNING A. SMITH.
   Use of 3-trifluormethyl-4-nitrophenol as a selective sea lamprey larvicide. Great Lakes Fishery Commission, Technical Report No. 1, 35 p., May 1961.
   Ann Arbor

3. BARKLEY, RICHARD A., AND THOMAS S. AUSTIN.
   Distribution of properties about the equatorial undercurrent. Abstracts of Symposium Papers, Tenth Pacific Science Congress, Symposium on Equatorial Circulation in the Pacific, p. 339-340, September 1961.
   Hon

4. BARRETT, IZADORE, AND GERALD V. HOWARD.
   Studies on the age, growth, sexual maturity, and spawning of populations of anchoveta (*Cetengraulis mysticetus*) of the coast of the eastern tropical Pacific Ocean. Inter-American Tropical Tuna Commission Bulletin, vol. 5, no. 2, p. 115-216, March 1961.
   S.D.

5. BATES, DANIEL W., AND STANLEY G. JEWETT, JR.
   Louver efficiency in deflecting downstream migrant steelhead. Transactions of the American Fisheries Society, vol. 90, no. 3, p. 336-337, July 1961.
   BCF Columbia Prog. Oregon

6. BEETON, ALFRED M.
   Environmental changes in Lake Erie. Transactions of the American Fisheries Society, vol. 90, no. 2, p. 153-159, April 1961.
   Ann Arbor

7. BEETON, ALFRED M., AND FRANK F. HOOPER.
   The hydrography of Saginaw Bay (Abstract). Proceedings of the Fourth Conference on Great Lakes Research, Great Lakes Research Division, Institute of Science and Technology, University of Michigan, Publication No. 7, p. 111, November 1961.
   Ann Arbor

8. BERRY, FREDERICK H., AND MAX POLL.
   Synonymy of the Atlantic Ocean filefish *Alutera heudeloth* Hollard. Copeia, no. 3, p. 360-362, September 22, 1961.
   L.J.

9. BERRY, FREDERICK H., AND WILLIAM W. ANDERSEN.
Stargazer fishes from the western North Atlantic (family Uranoscopidae). Proceedings of the United States National Museum, vol. 112, no. 3448, p. 563-586, April 1961.

10. BLAHM, T. H.
Effect of tricaine methanesulfonate on oxygen consumption of juvenile sockeye salmon. Transactions of the American Fisheries Society, vol. 90, no. 2, p. 226-227, April 1961.

11. BOYAR, H. C.
Swimming speed of immature Atlantic herring with reference to the Passamaquoddy tidal project. Transactions of the American Fisheries Society, vol. 90, no. 1, p. 21-26, January 1961.

12. BUETTNER, HOWARD J.
Recoveries of tagged, hatchery-reared lake trout from Lake Superior. Transactions of the American Fisheries Society, vol. 90, no. 4, p. 404-412, October 1961.

13. BUTLER, PHILIP A.
Effects of pesticides on commercial fisheries. Proceedings of the Gulf and Caribbean Fisheries Institute, 13th Annual Session, November 1960, p. 168-171, April 1961.

14. CALDWELL, DAVID K.
Populations of the butterfish, *Poronotus triacanthus* (Peck), with systematic comments. Bulletin of the Southern California Academy of Sciences, vol. 60, part 1, p. 19-31, May 1961.

15. CALDWELL, DAVID K., AND MELBA C. CALDWELL.
Gray squirrels larcenously feeding at cracker-vending machines. Quarterly Journal of the Florida Academy of Science, vol. 23, no. 4, p. 285-288, March 1961.

16. CARRIKER, MELBOURNE R.
Interrelation of functional morphology, behavior, and autecology in early stages of the bivalve *Mercenaria mercenaria*. Journal of the Elisha Mitchell Scientific Society, vol. 77, no. 2, p. 168-241, November 1961.

17. CARRIKER, MELBOURNE R.
Comparative functional morphology of boring mechanisms in gastropods. American Zoologist, vol. 1, no. 2, p. 263-266, May 1961.

18. CHANLEY, PAUL E.
Inheritance of shell markings and growth in the hard clam, *Venus mercenaria*. Proceedings of the National Shellfisheries Association, vol. 50, 1959, p. 163-169, June 1961.

19. CHAPOTON, ROBERT B., AND JAMES E. SYKES.
Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. Transactions of the American Fisheries Society, vol. 90, no. 1, p. 13-20, January 1961.

20. COHEN, DANIEL M.
On the identity of the species of the genus Argentina in the Indian Ocean. Galathea Report, vol. 5, Scientific Results of the Danish Deep-Sea Expedition Round the World 1950-52, Danish Science Press, Ltd., Copenhagen, p. 19-22, November 1961.

21. COHEN, DANIEL M.
A new genus and species of deepwater ophidioid fish from the Gulf of Mexico. Copeia, no. 3, p. 288-292, September 22, 1961.

22. COLTON, JOHN B.
The distribution of eyed flounder and lanternfish larvae in the Georges Bank area. Copeia, no. 3, p. 274-279, September 22, 1961.

23. COLTON, JOHN B., K. A. HONEY, AND R. F. TEMPLE.
The effectiveness of sampling methods used to study the distribution of larval herring in the Gulf of Maine. Journal du Conseil, vol. 26, no. 2, p. 180-190, April 1961.

24. COLTON, JOHN B., AND ROBERT F. TEMPLE.
The enigma of Georges Bank spawning. Limnology and Oceanography, vol. 6, no. 3, p. 280-291, July 1961.

25. COUNTS, ROBERT C.
A device for measuring larval and juvenile fishes. Copeia, no. 2, p. 224-226, June 19, 1961.

26. CRAIG, WILLIAM L., AND JOSEPH J. GRAHAM.
Report on a co-operative preseason survey of the fishing grounds for albacore (*Thunnus germo*) in the eastern North Pacific, 1959. California Fish and Game, vol. 47, no. 1, p. 73-85, January 1961.

27. DAVIS, HARRY C., AND RAVENNA UKELES.
Mass culture of phytoplankton as foods for metazoans. Science, vol. 134, no. 3478, p. 562-564, August 25, 1961.

28. DiCOSTANZO, CHARLES J., AND MURRAY L. HAYES.
A method of separating river stocks of red salmon in the Bristol Bay fishery. Science in Alaska - 1960, Proceedings of the Eleventh Alaskan Science Conference, p. 102-103, May 1961.

29. EBER, L. E.
Effects of wind induced advection on sea surface temperature. Journal of Geophysical Research, vol. 66, no. 3, p. 839-844, March 1961.

30. EDWARDS, ROBERT L.
The fishes of Richmond Gulf, Ungava, Canada. Proceedings of the American Philosophical Society, vol. 105, no. 2, p. 196-205, April 1961.

31. EDWARDS, ROBERT L.
Studies of the Philopteridae (Mallophaga) from birds of the order Procellariformes. 1. The genus Halipeurus Thompson. Journal of Parasitology, vol. 47, no. 1, p. 125-157, February 1961.

32. EDWARDS, ROBERT L., AND J. L. CHAMBERLIN.
Grant number 1547 (1953), $1,500. Ecological investigation of Richmond Gulf, Hudson Bay. Year Book of the American Philosophical Society, p. 285-287, December 1961.

33. FAVORITE, FELIX.
Pacific subarctic circulation (Abstract). Abstracts of Symposium Papers, Tenth Pacific Science Congress, Honolulu, Hawaii, p. 343-344, September 1961.

34. FAVORITE, FELIX.
Surface temperature and salinity off the Washington and British Columbia coasts, August 1958 and 1959. Journal of the Fisheries Research Board of Canada, vol. 18, no. 3, p. 311-319, May 1961.

35. FINUCANE, JOHN H., AND BILLIE Z. MAY.
Modified van Dorn water sampler. Limnology and Oceanography, vol. 6, no. 1, p. 85-87, January 1961.

36. FISCUS, CLIFFORD H.
Growth in the Stellar sea lion. Journal of Mammalogy, vol. 42, no. 2, p. 218-223, May 20, 1961.

37. FRITZ, RAYMOND L.
Size distribution by depth of the longfin hake, *Phycis chesteri*. Copeia, no. 2, p. 229-230, June 19, 1961.

38. GALTSOFF, PAUL S.
The three hearts of the oyster. Proceedings of the National Shellfisheries Association, vol. 51, p. 7-11, May 1961.

39. GALTSOFF, PAUL S.
Physiology of reproduction in molluscs. American Zoologist, no. 1, p. 273-289, February 1961.

40. GLUDE, JOHN B.
The future of the United States oyster industry from a biologist's viewpoint. Proceedings of the Gulf and Caribbean Fisheries Institute, 13th Annual Session, November 1960, p. 131-134, April 1961.

41. GORDON, WILLIAM G.
Food of the American smelt in Saginaw Bay, Lake Huron. Transactions of the American Fisheries Society, vol. 90, no. 4, p. 439-443, October 1961.

42. HARTMAN, WILBUR L.
Reproductive behavior of North American sticklebacks. *IN* High School Biology, Biological Investigations for Secondary School Students, American Institute of Biological Sciences, New York, p. 145-146, January 1961.

43. HATCH, RICHARD W.
Regular occurrence of false annuli in four brook trout populations. Transactions of the American Fisheries Society, vol. 90, no. 1, p. 6-12, January 1961.

44. HAYES, M. L.
Biological research and the economics of commercial fisheries in Alaska. Science in Alaska - 1960, Proceedings of the Eleventh Alaskan Science Conference, p. 141-142, May 1961.

45. HEBARD, JAMES F.
Currents in southeastern Bering Sea. International North Pacific Fisheries Commission Document No. 281, Bulletin No. 5, p. 9-16, August 1961. [Also published as SSR-F No. 293, April 1959.]

✓ 46. HESTER, FRANK J.
Tuna seines: How deep? Pacific Fisherman, November 1961.

✓ 47. HESTER, FRANK J.
A method of predicting tuna catch by using coastal sea-surface temperatures. California Fish and Game, vol. 47, no. 4, p. 313-326, October 1961.

✓ 48. HOESE, H. D., C. E. RICHARDS, AND M. CASTAGNA.
Appearance of the gag, Mysteroperca microlepis, in coastal waters of Virginia. Chesapeake Science, vol. 2, nos. 1 and 2, p. 104-105, March-June 1961.

✓ 49. HOWARD, GERALD V.
The Pacific coast tuna fisheries. Western Fisheries, p. 1-7, May 1961.

✓ 50. JACOBY, CARL.
Relative growth of fins in the fourhorn sculpin, Myoxocephalus quadricornis from the upper Great Lakes. Copeia, no. 4, p. 473-475, December 19, 1961.

✓ 51. JENSEN, ALBERT C.
Recaptures of tagged spiny dogfish, Squalus acanthias. Copeia, no. 2, p. 228-229, June 19, 1961.

✓ 52. JENSEN, ALBERT C.
Scientists forecast improved catch of haddock on Georges during 1961. National Fisherman and Maine Coast Fisherman, vol. 41, no. 12, p. 10, March 1961.

✓ 53. JENSEN, ALBERT C., AND JOHN P. WISE.
Movement of tagged halibut off New England--II. Transactions of the American Fisheries Society, vol. 90, no. 4, p. 489-490, October 1961.

✓ 54. JONES, WALTER G., AND GEORGE Y. HARRY, JR.
The Oregon trawl fishery for mink food--1948-1957. Research Briefs, Fish Commission of Oregon, vol. 8, no. 1, p. 14-30, August 1961.

✓ 55. KELLY, GEORGE F., AND ALLAN M. BARKER.
Observations on the behavior, growth, and migration of redfish at Eastport, Maine. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procéedings-Verbaux des Reunion, vol. 150, p. 263-275, November 1961.

56. KELLY, GEORGE F., AND ALLAN M. BARKER.
Vertical distribution of young redfish in the Gulf of Maine. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Proceedings-Verbaux des Reunion, vol. 150, p. 220-233, November 1961.

57. KELLY, GEORGE F., ALLAN M. BARKER, AND GEORGE M. CLARKE.
Racial comparisons of redfish from the western North Atlantic and the Barents Sea. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Proceedings-Verbaux des Reunion, vol. 150, p. 28-41, November 1961.

58. KENYON, KARL W., AND DALE W. RICE.
Abundance and distribution of the Steller sea lion. Journal of Mammalogy, vol. 42, no. 2, p. 223-234, May 1961.

59. LEWIS, ROBERT M.
Comparison of three tags on striped bass in the Chesapeake Bay area. Chesapeake Science, vol. 2, nos. 1 and 2, p. 3-8, March-June 1961.

60. LOOSANOFF, VICTOR L.
Recent advances in the control of shellfish predators and competitors. Proceedings of the Gulf and Caribbean Fisheries Institute, 13th Annual Session, November 1960, p. 113-127, April 1961.

61. LOOSANOFF, VICTOR L.
Partial metamorphosis in anomia simplex. Science, vol. 133, no. 3470, p. 2070-2071, June 30, 1961.

62. LUX, FRED E.
Bureau studies yellowtails to balance market here. Sunday Standard Times, New Bedford, Massachusetts, p. 17, February 26, 1961.

63. McGARY, JAMES W., JOSEPH J. GRAHAM, AND TAMIO OTSU.
Oceanography and North Pacific albacore. California Cooperative Oceanic Fisheries Investigations, Reports vol. 8, July 1, 1959 to June 30, 1960, p. 45-53, January 1961.

64. McHUGH, J. L.
Power from the tides. Sea Frontiers, Magazine of the National Oceanographic Foundation, vol. 7, no. 1, p. 30-40, February 1961.

65. McLAUGHLIN, PATSY A., AND JAMES F. HEBARD.
Stomach contents of the Bering Sea king crab. International North Pacific Fisheries Commission Document No. 280, Bulletin No. 5, p. 5-8, August 1961. [Also published as SSR-F No. 291, April 1959.]

Volume II

√ 66. MacKENZIE, JR., CLYDE L., AND L. W. SHEARER.
Chemical control of *Polydora websteri* and other annelids inhabiting oyster shells. Proceedings of the National Shellfisheries Association, vol. 50, p. 105-111, June 1961.

√ 67. MATSUMOTO, WALTER M.
Collection and descriptions of juvenile tunas from the central Pacific. Deep-Sea Research, vol. 8, nos. 3 and 4, p. 279-285, February 1961.

√ 68. MEAD, GILES W., AND CARL J. SINDERMANN.
Systematics and natural marks. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Proceedings-Verbaux des Reunion, vol. 150, p. 9-11, December 1961.

√ 69. MERRELL, THEODORE R.
Survival of pink salmon at Little Port Walter Research Station. Science in Alaska - 1960, Proceedings of the Eleventh Alaskan Science Conference, p. 99-102, May 1961.

√ 70. MERRILL, ARTHUR S.
Remarks concerning the benefits of systematic and repetitive collecting from navigation buoys (Abstract). American Malacological Union, Buffalo Museum of Science, Bulletin No. 27, p. 26, January 1, 1961.

√ 71. MERRILL, ARTHUR S.
Some observations on the growth and survival of organisms in the shell of *Placopecten magellanicus* (Abstract). American Malacological Union, Bulletin No. 28, p. 4-5, December 1, 1961.

√ 72. MERRILL, ARTHUR S.
Shell morphology in the larval and postlarval stages of the sea scallop, *Placopecten magellanicus* (Gmelin). Bulletin of the Museum of Comparative Zoology, vol. 125, no. 1, p. 3-20, March 1961.

√ 73. MERRILL, ARTHUR S.
The sea scallop fishery (Abstract). American Malacological Union, Bulletin No. 28, p. 14, December 1, 1961.

√ 74. MILLER, DAVID.
A modification of the small hardy plankton sampler for simultaneous high-speed plankton hauls. Marine Ecology, vol. 5, no. 45, p. 165-172, July 1961.

75. NAKAMURA, EUGENE L., AND HEENY S. H. YUEN.
Incidence of the giant trematode, *Hirudinella marina* Garcin in skipjack tuna, *Euthynnus pelamis* (Linnaeus), from Marquesan and Hawaiian waters. Transactions of the American Fisheries Society, vol. 90, no. 4, p. 419-423, October 1961.

76. NORDEN, CARROLL R.
The identification of larval yellow perch, *Perca flavescens* and walleye, *Stizostedion vitreum*. Copeia, no. 3, p. 282-288, September 22, 1961.

77. PROVENZANO, ANTHONY J., JR.
Effects of the flatworm *Stylochus ellipticus* (Girard) on oyster spat in two salt water ponds in Massachusetts. Proceedings of the National Shellfisheries Association, vol. 50, p. 83-88, June 1961.

78. PYCHA, RICHARD L.
Recent changes in the walleye fishery of northern Green Bay and history of the 1943 year class. Transactions of the American Fisheries Society, vol. 90, no. 4, p. 475-488, October 1961.

79. REINTJES, JOHN W., AND FRED C. JUNE.
A challenge to the fish meal and oil industry in the Gulf of Mexico. Proceedings of the Gulf and Caribbean Fisheries Institute, 13th Annual Session, p. 62-66, April 1961.

80. RICE, DALE W.
Sei whales with rudimentary baleen. Norsk Hvalfangst-Tidende, vol. 50, no. 5, p. 189-193, May 1961.

81. RICE, DALE W.
Census of the California gray whale, 1959/60. Norsk Hvalfangst-Tidende, vol. 50, no. 6, p. 219-225, June 1961.

82. RICE, DALE W., AND DAVID K. CALDWELL.
Observations on the habits of the whalesucker (*Remilegia australis*). Norwegian Whaling Gazette, vol. 50, no. 5, p. 181-189, May 1961.

83. RIDGWAY, GEORGE J.
Special immunological techniques for the study of marine populations (Abstract). Abstracts of Symposium Papers, Tenth Pacific Science Congress, Honolulu, Hawaii, p. 184-185, September 1961.

√ 84. RIDGWAY, GEORGE J., AND GEORGE W. KLONTZ.
Blood types in Pacific salmon. International North Pacific Fisheries Commission Document No. 360, Bulletin No. 5, p. 49-55, August 1961. [Also published as SSR-F No. 324, January 1960.]

√ 85. RIDGWAY, GEORGE J., J. E. CUSHING, AND G. L. DURALL.
Serological differentiation of populations of sockeye salmon, *Oncorhynchus nerka*. International North Pacific Fisheries Commission Document No. 270, Bulletin No. 3, p. 5-10, January 1961. [Also published as SSR-F No. 257, August 1958.]

√ 86. ROPES, JOHN W.
Longevity of the horseshoe crab, *Limulus polyphemus* (L.) Transactions of the American Fisheries Society, vol. 90, no. 1, p. 79-80, January 1961.

√ 87. ROUNSEFELL, GEORGE A.
How can research production be measured? Proceedings of the Gulf and Caribbean Fisheries Institute, 13th Annual Session, November 1960, p. 139-150, April 1961.

√ 88. SAKUDA, HENRY M.
Observations of molting female king crabs, *Paralithodes camtschatica* (Telesius). International North Pacific Fisheries Commission Document No. 271, Bulletin No. 5, p. 1-4, August 1961. [Also published as SSR-F No. 274, July 1958.]

√ 89. SAUR, J. F. T.
On the differences between sea water temperatures from ship's weather observations and sea surface temperatures. Journal of Geophysical Research, vol. 66, no. 5, p. 1558-1559, May 1961.

√ 90. SETTE, OSCAR E.
Problems in fish population fluctuations. California Cooperative Oceanic Fisheries Investigations, Reports vol. 8, July 1, 1959 to June 30, 1960, p. 21-24, January 1961.

√ 91. SCATTERGOOD, LESLIE W.[1]
Maine sharks. IN A Cruising Guide to the New England Coast including the Hudson River, Long Island Sound and the Coast of New Brunswick, p. 463-467, by Roger F. Duncan and Fessenden S. Blanchard, Fifth Edition, Dodd, Mead, and Company, 478 p.

---

[1] Reprint not available.

92. SHEARER, L. W., AND C. L. MacKENZIE, JR.
The effects of salt solutions of different strengths on oyster enemies. Proceedings of the National Shellfisheries Association, vol. 50, p. 97-103, June 1961.

93. SHERMAN, KENNETH.
A high school oceanographic laboratory. The American Biology Teacher, vol. 23, no. 1, p. 29-35, January 1961.

94. SHERMAN, KENNETH.
Occurrence of early developmental stages of the oblong ocean sunfish *Rangania laevis* (Pennant) in the central North Pacific. Copeia, no. 4, p. 467-470, December 19, 1961.

95. SHERMAN, KENNETH, AND JOHN P. WISE.
Incidence of the cod parasite *Lernaeocera branchilalis* L. in the New England area, and its possible use as an indicator of cod populations. Limnology and Oceanography, vol. 6, no. 1, p. 61-67, January 1961.

96. SINDERMANN, CARL J.
Serological techniques in fishery research. Transactions of the 26th North American Wildlife Conference, p. 298-309, March 1961.

97. SINDERMANN, CARL J.
Sporozoan parasites of sea herring (Abstract). Journal of Parasitology, vol. 47, no. 4, p. 34, August 1961.

98. SINDERMANN, CARL J.
Serological studies of redfish (Abstract). Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procéedings-Verbaux des Reunion, vol. 150, p. 118, September 1961. [Also as Fishery Bulletin 191.]

99. SINDERMANN, CARL J.
Parasitological tags for redfish of the western North Atlantic. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procéedings-Verbaux des Reunion, vol. 150, p. 111-117, September 1961.

100. SINDERMANN, CARL J.
Isoagglutination in elasmobranch fishes (Abstract). American Zoologist, vol. 1, no. 3, p. 260[illegible] August 1961.

101. SINDERMANN, CARL J.
The effect of larval trematode parasites on snail migrations. American Zoologist, vol. 1, no. 3, p. 259, August 1961.

102. SINDERMANN, CARL J.
Parasite tags for marine fish. Journal of Wildlife Management, vol. 25, no. 1, p. 41-47, January 1961.

103. SINDERMANN, CARL J., AND DONALD F. MAIRS.
A blood group system for spiny dogfish, *Squalus acanthias* L. Biological Bulletin, vol. 120, no. 3, p. 401-410, June 1961.

104. SKERRY, JOHN B.
An eastward extension of the winter movement of mackerel, *Scomber scombrus*. Copeia, no. 1, p. 155, March 17, 1961.

105. SKUD, BERNARD E.
Education and recruitment of oceanographers in the United States. (Report by the Committee on Education and Recruitment, American Society of Limnology and Oceanography, Inc.). Transactions of the American Fisheries Society, vol. 90, no. 2, p. 232, April 1961.

106. SMITH, JR., LLOYD L., AND RICHARD L. PYCHA.
Factors related to commercial production of the walleye in Red Lakes, Minnesota. Transactions of the American Fisheries Society, vol. 90, no. 2, p. 190-217, April 1961.

107. SMITH, MANNING A., VERNON C. APPLEGATE, AND B. G. H. JOHNSON.
Physical properties of some halo-nitrophenols. Journal of Chemical and Engineering Data, vol. 6, no. 4, p. 607-608, October 1961.

108. SMITH, STANFORD H., HOWARD J. BUETTNER, AND RALPH HILE.
Fishery statistical districts of the Great Lakes. Great Lakes Fishery Commission, Technical Report No. 2, 24 p., September 1961.

109. SPRAGUE, LUCIAN M.
Erythrocyte antigens of the oceanic skipjack (*Katsuwonus pelamis*) recognized by phytoagglutinens (Abstract). Records of the Genetics Society of America, no. 30, p. 111, August 1961. [Also in Genetics, vol. 46, no. 8, p. 901.]

110. SPRAGUE, LUCIAN M., AND LESLIE I. NAKASHIMA.
Studies on the erythrocyte antigens of the skipjack tuna (Katsuwonus pelamis). Abstracts of Symposium Papers, Tenth Pacific Science Congress, Symposium on Immunogenetic Concepts in Marine Population Research, p. 186, September 1961.

111. STERN, JOSEPH A., DIPTIMAN CHAKRAVARTI, JOSEPH R. UZMAN, AND MARY N. HESSELHOLT.
Rapid counting of nematoda in salmon by peptic digestion. International North Pacific Fisheries Commission Document No. 180, Bulletin No. 3, 4 p., January 1961. /Also published as SSR-F No. 255, May 1958./

112. STRASBURG, DONALD W.
Larval carapid fishes from Hawaii with remarks on the ecology of adults. Copeia, no. 4, p. 478-480, December 19, 1961.

113. STRASBURG, DONALD W.
Diving behavior of Hawaiian skipjack tuna. Journal du Conseil, vol. 26, no. 2, p. 223-229, April 1961.

114. STRASBURG, DONALD W., AND JOHN C. MARR.
Banded color phases of two pelagic fishes, Coryphaena hippurus and Katsuwonus pelamis. Copeia, no. 2, p. 226-228, June 19, 1961.

115. SYKES, JAMES E.
The Chesapeake Bay cooperative striped bass program. Chesapeake Science, vol. 2, nos. 1 and 2, 2 p., March-June 1961.

116. TAGATZ, MARLIN E.
Reduced oxygen tolerance and toxicity of petroleum products to juvenile American shad. Chesapeake Science, vol. 2, nos. 1 and 2, p. 65-71, March-June 1961.

117. TALBOT, GERALD B.
At Hatteras' back door. Sea Frontiers, vol. 7, no. 2, p. 103-112, May 1961.

118. UCHIDA, RICHARD N.
Hermaphroditic skipjack. Pacific Science, vol. 15, p. 294-296, April 1961.

119. UKELES, RAVENNA.
The effect of temperature on the growth and survival of several marine algal species. Biological Bulletin, vol. 120, no. 2, p. 255-264, April 1961.

120. VAN OOSTEN, JOHN.
Records, ages, and growth of the mooneye, Hioden tergisus, of the Great Lakes. Transactions of the American Fisheries Society, vol. 90, no. 2, p. 170-174, April 1961.

121. WALBURG, CHARLES H.
Natural mortality of American shad. Transactions of the American Fisheries Society, vol. 90, no. 2, p. 228-230, April 1961.

122. WEBER, KING G.
The status of fish passage in the Pacific northwest (Abstract). Abstracts of Symposium Papers, Tenth Pacific Science Congress, Honolulu, Hawaii, p. 151-152, September 1961.

123. WEBSTER, JOHN R., AND ROYSTON Z. MEDFORD.
Flatworm distribution and associated oyster mortality in Chesapeake Bay. Proceedings of the National Shellfisheries Association, 1959, vol. 50, p. 89-95, June 1961.

124. WIGLEY, ROLAND L.
A new isopod, Chiridotea nigrescens, from Cape Cod, Massachusetts, Crustaceana, vol. 2, part 4, p. 286-292, January 1961.

125. WIGLEY, ROLAND L.
Bottom sediments of Georges Bank. Journal of Sedimentary Petrology, vol. 31, no. 2, p. 165-188, June 1961.

126. WIGLEY, ROLAND L.
Natural history of a selected species of marine invertebrate. IN High School Biology, Biological Investigations for Secondary School Students, p. 381-383, June 1961.

127. WIGLEY, ROLAND L.
Benthic fauna of Georges Bank. Transactions of the Twenty-sixth North American Wildlife and Natural Resources Conference, p. 310-317, March 1961.

128. WILIMOVSKY, NORMAN J.
An application of radioactive isotopes in fish tagging. Science in Alaska, 1960, Proceedings of the Eleventh Alaskan Science Conference, p. 93-99, May 1961.

129. WILKE, FORD, AND CLIFFORD H. FISCUS.
Gray whale observations. Journal of Mammalogy, vol. 42, no. 1, p. 108-109, February 20, 1961.

130. WOLF, ROBERT S., AND ANITA E. DAUGHERTY.
Age and length composition of the sardine catch off the Pacific coast of the United States and Mexico in 1958-59. California Fish and Game, vol. 47, no. 3, p. 273-285, July 1961.

131. WOOSTER, WARREN S.
Yearly changes in the Peru current. Limnology and Oceanography, vol. 6, no. 2, p. 222-226, April 1961.

132. WOOSTER, WARREN S.
Further evidence of a Pacific south equatorial countercurrent. Deep-Sea Research, vol. 8, nos. 3 and 4, p. 294-297, June 1961.

133. YUEN, HEENY S. H.
Bow wave riding of dolphins. Science, vol. 134, no. 3484, p. 1011-1012, May 1, 1961.

134. ZEIN-ELDIN, ZOULA P.
Plankton pigments in east Lagoon, Galveston, Texas. Transactions of the American Fisheries Society, vol. 90, no. 1, p. 32-41, January 1961.

REPRINTS OF CONTRACTORS APPEARING IN OTHER THAN FISH AND WILDLIFE SERVICE PUBLICATIONS.

135. HARGIS, WILLIAM J., JR., AND CLYDE L. MacKENZIE, JR.
Sexual behavior of the oyster drills: *Eupleura caudata* and *Urosalpinx cinerea*. Nautilus, vol. 75, no. 1, p. 7-16, July 1961.

136. HOLMES, ROBERT W., AND JAMES M. SNODGRASS.
A multiple-detector irradiance meter and electronic depth sensing unit for use in biological oceanography. Journal of Marine Research, vol. 19, no. 1, p. 40-56, March 15, 1961.

137. MacKENZIE, JR., CLYDE L.
Growth and reproduction of the oyster drill, *Eupleura caudata*, in the York River, Virginia. Ecology, vol. 42, no. 2, p. 317-338, April 1961.

138. POWERS, CHARLES F., DAVID L. JONES, PAUL C. MUNDINGER, AND JOHN C. AYERS.
Application of data collected along shore to conditions in Lake Erie. Great Lakes Research Division, Institute of Science and Technology, University of Michigan, Publication No. 5, 78 p., February 1961.

139. RODEN, GUNNAR I.
On the wind-driven circulation in the Gulf of Tehuantepec and its effects upon surface temperatures. Geofisica Internacional, Mexico, vol. 1, no. 3, p. 55-76 (English and Spanish), October 1961.

140. WOOSTER, WARREN S., AND MALVERN GILMARTIN.
The Peru-Chile undercurrent. Journal of Marine Research, vol. 19, no. 3, p. 97-122, November 1961.

PAPERS PUBLISHED IN 1960 NOT INCLUDED IN THE 1960 VOLUME OF COLLECTED REPRINTS.

✓141. COUTURE, LAWRENCE H.
I. ICNAF mesh regulations, operation of ten percent annual exemption October 1, 1957 through September 30, 1959. Annual Proceedings of the International Commission for the Northwest Atlantic Fisheries, vol. 10, 1959-60, p. 120-122, December 1960.

142. GRAHAM, HERBERT W.
XI. United States research in the convention area during 1959. Annual Proceedings of the International Commission for the Northwest Atlantic Fisheries, vol. 10, 1959-60, p. 112-115, December 1960.

143. MARAK, ROBERT R.
Food habits of larval cod, haddock, and coalfish in the Gulf of Maine and Georges Bank area. Journal du Conseil, vol. 25, no. 2, p. 147-157, March 1960.

✓144. SCHWARTZ, FRANK J., MICHAEL CASTAGNA, AND GEORGE GRIFFITH.
Comments on the abundance and ecology of the Ascidian *Amaroucium constellatum* in Sinepuxent and Chincoteague Bays. Chesapeake Science, vol. 1, nos. 3 and 4, p. 197-199, December 1960.

LIST OF
REPORTS OF THE DIVISION OF BIOLOGICAL RESEARCH
APPEARING IN PUBLICATIONS OF THE FISH AND WILDLIFE SERVICE - 1961

CIRCULARS

1. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS.
   Galveston Biological Laboratory, fishery research for the year ending June 30, 1961. U.S. Fish and Wildlife Service, Circular 129, iii + 82 p., July 1961.

2. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU, HAWAII.
   Progress in 1960. U.S. Fish and Wildlife Service, Circular 127, 31 p., November 1961.

3. COHEN, DANIEL M.
   Research program of the Ichthyological Laboratory, U.S. Fish and Wildlife Service, Circular 124, 8 p., July 1961.

4. DUNCAN, THOMAS O.
   The Pacific Region of the Bureau of Commercial Fisheries. U.S. Fish and Wildlife Service, Circular 108, 17 p., May 1961.

COMMERCIAL FISHERIES REVIEW

1. DAVIS, HARRY C.
   Effects of some pesticides on eggs and larvae of oysters (Crassostrea virginica) and clams (Venus mercenaria). U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 23, no. 12, p. 8-23, December 1961.

2. GRAHAM, JOSEPH J., AND JAMES W. McGARY.
   Investigations of the potential albacore resource of the central North Pacific. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 23, no. 11, p. 1-7, November 1961. /Also as Separate No. 631./

3. HASKELL, WINTHROP A.
   Gulf of Mexico trawl fishery for industrial species. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 23, no. 2, p. 1-6, February 1961.

COMMERCIAL FISHERIES REVIEW (Cont'd)

√4. MacKENZIE, JR., CLYDE L.
A practical method for killing mussels and other oyster competitors. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 23, no. 3, p. 15-19, March 1961.

FISHERY BULLETINS

√1. BERRY, FREDERICK H., AND LOUIS E. VOGELE.
Filefishes (Monacanthidae) of the western North Atlantic. U.S. Fish and Wildlife Service, Fishery Bulletin 181, vol. 61, iv + p. 61-109, April 1961.

√2. JUDY, MAYO H.
Validity of age determination from scales of marked American shad. U.S. Fish and Wildlife Service, Fishery Bulletin 185, vol. 61, iv + p. 161-170, January 1961.

3. MARVIN, KENNETH T., LARENCE M. LANSFORD, AND RAY S. WHEELER.
Effects of copper ore on the ecology of a Lagoon. U.S. Fish and Wildlife Service, Fishery Bulletin 184, vol. 61, iv + p. 143-160, November 1961.

√4. PIAVIS, GEORGE W.
Embryological stages in the sea lamprey and effects of temperature on development. U.S. Fish and Wildlife Service, Fishery Bulletin 182, vol. 61, iv + p. 111-143, March 1961.

√5. SINDERMANN, CARL J.
Serological studies of Atlantic redfish. U.S. Fish and Wildlife Service, Fishery Bulletin 191, vol. 61, iv + p. 351-354, January 1961.

√6. SINDERMANN, CARL J., AND DONALD F. MAIRS.
Blood properties of prespawning and postspawning anadromous alewives. U.S. Fish and Wildlife Service, Fishery Bulletin 183, vol. 61, iv + p. 145-151, November 1961.

FISHERY LEAFLETS

1. DEES, LOLA T.
A list of the Fishery Bulletins of the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service, Fishery Leaflet 509, 14 p., March 1961.

2. DEES, LOLA T.
United States Fish and Wildlife Service publications on limnology, 1940-1960. U.S. Fish and Wildlife Service, Fishery Leaflet 512, 7 p., April 1961.

3. DEES, LOLA T.
Rains of fishes. U.S. Fish and Wildlife Service, Fishery Leaflet 513, 5 p., April 1961.

4. DEES, LOLA T.
List of Special Scientific Reports (Nos. 1-67) and Special Scientific Report--Fisheries (Nos. 1-). U.S. Fish and Wildlife Service, Fishery Leaflet 514, 35 p., April 1961.

5. DEES, LOLA T.
United States Fish and Wildlife Service publications on oceanography. U.S. Fish and Wildlife Service, Fishery Leaflet 515, 14 p., April 1961.

6. DEES, LOLA T.
Ambergris. U.S. Fish and Wildlife Service, Fishery Leaflet 517, 7 p., May 1961.

7. DEES, LOLA T.
A list of the Circulars of the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service, Fishery Leaflet 518, 8 p., June 1961.

8. DEES, LOLA T.
A list of research reports of the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service, Fishery Leaflet 519, 4 p., June 1961.

9. DEES, LOLA T.
Spiny lobsters. U.S. Fish and Wildlife Service, Fishery Leaflet 523, 8 p., September 1961.

10. DEES, LOLA T.
Cephalopods: Cuttlefish, octopuses, squids. U.S. Fish and Wildlife Service, Fishery Leaflet 524, 10 p., September 1961.

FISHERY LEAFLETS (Cont'd)

11. DEES, LOLA T.
The mosquitofish Gambusia affinis. U.S. Fish and Wildlife Service, Fishery Leaflet 525, 6 p., September 1961.

12. DEES, LOLA T.
Sturgeons. U.S. Fish and Wildlife Service, Fishery Leaflet 526, 8 p., September 1961.

13. DEES, LOLA T.
Brine shrimp. U.S. Fish and Wildlife Service, Fishery Leaflet 527, 5 p., September 1961.

14. JUNE, FRED C.
The menhaden fishery of the United States. U.S. Fish and Wildlife Service, Fishery Leaflet 521, 13 p., August 1961.

15. LOOSANOFF, VICTOR L.
Biology and methods of controlling the starfish, Asterias forbesi, (Desor). U.S. Fish and Wildlife Service, Fishery Leaflet 520, 11 p., July 1961.

16. SCATTERGOOD, LESLIE W.
The sea urchin fishery. U.S. Fish and Wildlife Service, Fishery Leaflet 511, 5 p., March 1961.

17. TALBOT, GERALD B.
The American shad. U.S. Fish and Wildlife Service, Fishery Leaflet 504, 8 p., February 1961.

PROGRESSIVE FISH-CULTURIST

1. BOUCHARD, LOYAL G., AND CHESTER R. MATTSON.
Immersion staining as a method of marking small salmon. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 23, no. 1, p. 34-40, January 1961.

2. BRAEM, ROBERT A., AND WESLEY J. EBEL.
A back-pack shocker for collecting lamprey ammocoetes. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 23, no. 2, p. 87-91, May 1961.

PROGRESSIVE FISH-CULTURIST (Cont'd)

3. CRADDOCK, DONOVAN R.
An improved trap for the capture and safe retention of salmon smolts. U.S. Fish and Wildlife Service, Progressive-Fish Culturist, vol. 23, no. 4, p. 190-192, October 1961.

4. PACHECO, ANTHONY L., AND GEORGE C. GRANT.
A frame used as a towing aid for small boats. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 23, no. 4, p. 161, October 1961.

5. WATSON, JOHN E.
The branding of sea herring as a short-term mark. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 23, no. 3, p. 105, July 1961.

6. WATSON, JOHN E.
Tricaine methanesulfonate as an anaesthetic for herring (Clupea larengus). U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 23, no. 4, p. 174, October 1961.

RESEARCH REPORT

1. WOLF, ROBERT S.
Age composition of the Pacific sardine, 1932-1960. U.S. Fish and Wildlife Service, Research Report 53, iv + 36 p., September 1961.

SPECIAL SCIENTIFIC REPORT--FISHERIES

1. ANDERSON, WILLIAM W., JOSEPH E. MOORE, AND HERBERT R. GORDY.
Water temperatures off the south Atlantic coast of the United States, Theodore N. Gill cruises 1-9, 1953-1954. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 380, vi + 206 p., May 1961.

2. APPLEGATE, VERNON C.
Downstream movement of lampreys and fishes in the Carp River, Michigan. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 387, iv + 71 p., August 1961.

SPECIAL SCIENTIFIC REPORT--FISHERIES (Cont'd)

3. CLARK, JOHN R., AND FRANK A. DREYER.
New England haddock fishery biostatistics - 1956. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 375, vi + 89 p., April 1961.

4. CONOVER, JOHN T., RAYMOND L. FRITZ, AND MANUEL VIEIRA.
A morphometric study of silver hake. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 368, iii + 13 p., January 1961.

5. DRAGOVICH, ALEXANDER.
Relative abundance of plankton off Naples, Florida, and associated hydrographic data, 1956-1957. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 378, iii + 41 p., January 1961.

6. DRAGOVICH, ALEXANDER, JOHN H. FINUCANE, AND BILLIE Z. MAY.
Counts of red tide organisms *Gymnodinium breve* and associated oceanographic data from Florida west coast, 1957-1959. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 369, iii + 175 p., January 1961.

7. FAVORITE, FELIX, RICHARD J. CALLAWAY, AND JAMES F. HEBARD.
North Pacific and Bering Sea oceanography, 1959. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 377, iv + 212 p., May 1961.

8. FAVORITE, FELIX, JOHN W. SCHANTZ, AND CHARLES R. HEBARD.
Oceanographic observations in Bristol Bay and the Bering Sea 1939-1941, (USCGT Redwing). U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 381, iii + 323 p., July 1961.

9. GRAHAM, JOSEPH J., AND WILLIAM L. CRAIG.
Oceanographic observations made during a cooperative survey of albacore (*Thunnus germo*) off the North American west coast in 1959. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 386, iv + 31 p., August 1961.

10. HOLMES, ROBERT W., AND ROBERT J. LINN.
A modified Beckman model DU spectrophotometer for seagoing use. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 382, iv + 4 p., July 1961.

SPECIAL SCIENTIFIC REPORT--FISHERIES (Cont'd)

11. JOHNSON, JAMES H.
S.D. Sea surface temperature monthly average and anomaly charts, northeastern Pacific Ocean 1947-1958. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 385, iii + 56 p., August 1961.

12. JUNE, FRED C.
Beaufort Age and size composition of the menhaden catch along the Atlantic coast of the United States, 1957. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 373, iv + 39 p., January 1961.

13. REID, GERALD M.
Juneau Stomach content analysis of troll-caught king and coho salmon, southeastern Alaska, 1957-1958. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 379, iii + 8 p., July 1961.

14. REINTJES, JOHN W.
Menhaden eggs and larvae from M/V Theodore N. Gill cruises, south Atlantic coast of the United States, 1953-1954. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 393, iv + 7 p., September 1961.

15. SHERMAN, KENNETH, AND ROBERT P. BROWN.
Oceanographic and biological data, Hawaiian waters, January-October 1959. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 396, iv + 71 p., December 1961.

16. TAGATZ, MARLIN E.
[illegible] Tolerance of striped bass and American shad to changes of temperature and salinity. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 388, iii + 8 p., August 1961.

17. TAGATZ, MARLIN E., AND DONNIE L. DUDLEY.
Seasonal occurrence of marine fishes in four shore habitats near Beaufort, North Carolina, 1957-1960. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 390, iii + 19 p., August 1961.

18. THORSTEINSON, FREDRIK V., RICHARD W. NELSON, AND DEXTER F. LALL.
Experimental harvest of the stellar sea lion in Alaskan waters. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 371, iii + 15 p., January 1961.

SPECIAL SCIENTIFIC REPORT--FISHERIES (Cont'd)

✓19. THRAILKILL, JAMES R.
Zooplankton volumes off the Pacific coast, 1958. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 374, ii + 70 p., January 1961.

✓20. WOLF, ROBERT S.
Graphic presentation of Pacific sardine egg composition data. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 384, 34 p., July 1961.

1

EXTRAIT

Rapp. et Proc.-Verb Vol. 150, 1961
Cons. Internat. Explor. de la Mer

1.

Distribution and Relative Abundance of Rockfish (*Sebastodes* spp.) Larvae off California and Baja California

By

ELBERT H. AHLSTROM
Fishery Research Biologist, U. S. Bureau of Commercial Fisheries
Biological Laboratory, La Jolla

The information presented in this paper concerns the distribution and abundance of *Sebastodes* larvae in the area off California and Baja California that is surveyed by agencies participating in the California Cooperative Oceanic Fisheries Investigations. The pelagic distribution of rockfish larvae, especially their presence at considerable distances offshore, should be of interest, since it parallels, in part at least, the widespread oceanic distribution of *Sebastes* larvae in the North Atlantic.

The fishery for rockfish off the Pacific coast of North America is not as important as the Atlantic fishery for *Sebastes.* In the early years of the fishery, between 1916 and 1935, California landings averaged about 6 million pounds per year (range, 4·6–8·2 million pounds), and landings in the Pacific Northwest were less than 1 million pounds. There was nearly a twelvefold expansion in the Pacific catch of rockfish between 1940 and 1945, the landings increasing from 5·2 to 60·4 million pounds. Most of the increase occurred off Oregon and Washington. Since World War II, annual landings have fluctuated around 25 million pounds (Table 1). It is interesting to note that there has been a slow but steady rise in the California landings during the past 10 years: the 1958 catch of 17·6 million pounds was the largest on record.

The rockfish marketed off Oregon and Washington as the Pacific ocean perch is *Sebastodes alutus*; this species is not common off California. The bocaccio, *Sebastodes paucispinis*, is the dominant species in the California catch. Other important species are *S. serranoides, S. crameri, S. entomelas, S. diploproa* and *S. ruberrimus.* Most of the above information was obtained from Phillips (1958).

As background information, a brief account is given of the hydrographic-biological survey cruises being conducted under the California Cooperative Oceanic Fisheries Investigations (CCOFI). A basic purpose of the cruises is to supply observations for an understanding of oceanographic conditions off California and Baja California. An equally important purpose is the collection of data for the study of the distribution, abundance, and fluctuations in pelagic marine fish populations, particularly of the Pacific sardine (*Sardinops caerulea*). The distribution and amount of sardine spawning as well as the survival of sardine larvae are assessed annually. Information on the pelagic stages of other marine fishes is a by-product of this investigation.

Table 1
Total annual landings of rockfish along the Pacific coast of North America (in millions of pounds)

Year	California	Oregon and Washington	British Columbia and Alaska	Total
1936	4·6	0·6	0·4	5·6
1937	4·3	0·6	0·2	5·1
1938	3·6	0·7	0·7	5·0
1939	3·3	0·7	0·3	4·3
1940	3·6	1·3	0·3	5·2
1941	3·4	2·4	0·6	6·4
1942	1·4	3·6	0·7	5·7
1943	2·8	12·3	2·5	17·6
1944	6·4	20·8	3·9	31·1
1945	13·3	42·6	4·5	60·4
1946	11·2	23·3	3·5	38·0
1947	8·5	13·3	0·8	22·6
1948	6·5	15·4	1·2	23·1
1949	6·1	17·7	1·6	25·4
1950	8·1	18·3	0·7	27·1
1951	11·0	16·0	0·9	27·9
1952	10·7	20·2	0·9	31·8
1953	12·2	12·0	0·5	24·7
1954	12·6	19·5	0·5	32·6
1955	12·7	13·1	0·5	26·3
1956	14·9	*)	*)	*)
1957	15·9	*)	*)	*)
1958	17·6	*)	*)	*)

*) Not available.

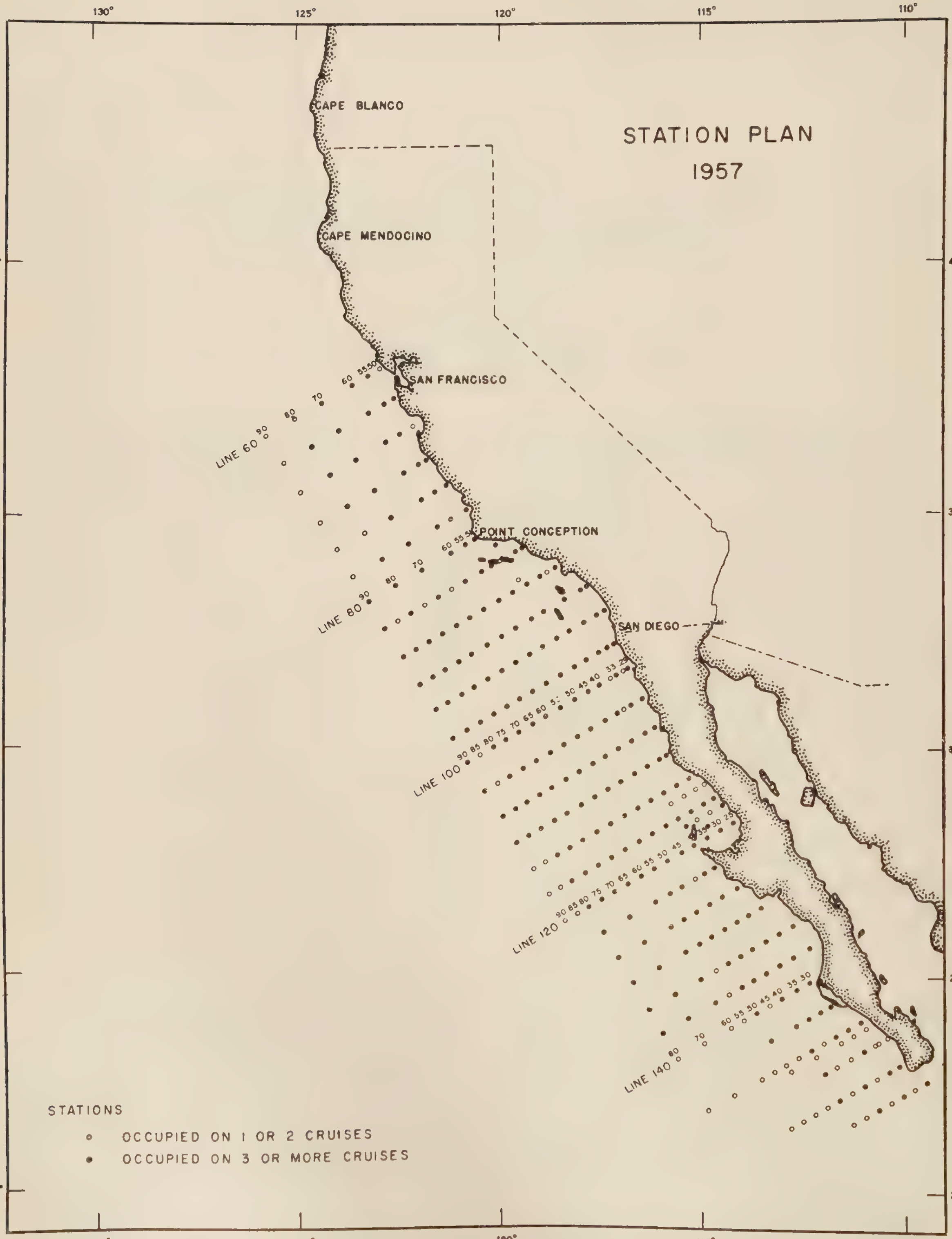

STATION PLAN
1957
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
LINE 60
LINE 80
LINE 100
LINE 120
LINE 140
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
STATIONS
○ OCCUPIED ON 1 OR 2 CRUISES
● OCCUPIED ON 3 OR MORE CRUISES

Figure 1. Station plan, 1957, of stations occupied on cruises of the California Cooperative Oceanic Fisheries Investigations.

Cruises are usually made at monthly intervals, 2 to 4 research vessels participating. The U.S. Bureau of Commercial Fisheries operates a single research vessel, the "Black Douglas"; the remainder are operated by the Scripps Institution of Oceanography. The survey area is illustrated in the Station Plan, 1957 (Figure 1). Coverage is usually rather extensive during the first seven months of each year, partial during the last five months. Stations in the principal spawning areas of the sardine, i.e. between Point Conception, California, and Point San Juanico, Baja California, are usually occupied 9 or 10 times during the year; stations off central California and southern Baja California are seldom occupied more than 3 to 5 times per year.

Fish eggs and larvae are collected in plankton nets hauled obliquely from a depth of about 140 m to the surface. The nets are 1 m in diameter at the mouth by approximately 5 m in overall length. The main straining portion of the nets is constructed of No. 30 grit gauze, a heavy grade of Swiss bolting silk; the posterior portion, including the detachable cod-end, of No. 56 grit gauze. The openings between threads in No. 30 grit gauze are approximately 0·70 mm before use, but shrink to approximately 0·55 mm after use.

In taking a plankton haul, the research vessel moves ahead at a slow speed, usually between 1½ and 2 knots. The net is fastened by a bridle to the towing cable at a point which is approximately 10 m above a 100 lb weight. The net is lowered to its greatest depth (200 m of cable out) in approximately 4 minutes and retrieved at a rate of approximately 20 m of cable per minute. The total towing time is thus between 14 and 15 minutes per haul. During each haul, an inclinometer is suspended from the boom, riding freely on the towing wire. The angle-of-stray of the towing wire from the vertical is recorded at one-half minute intervals. Vessel speed is adjusted as necessary during the haul to keep the angle-of-stray of the towing wire as close to 45° as is possible. The depth of the net at any instant during a haul can be approximated by multiplying the amount of tow wire out by the cosine of the angle-of-stray of the towing wire from the vertical. The usual depth of hauls is between 130 and 145 metres.

The amount of water strained during each haul is determined from the revolutions registered by a current meter fastened in the mouth of the net. Hauls are put on a comparable basis by expressing all counts as numbers in a column of water under 10 m^3 of sea surface. Estimates expressed in this way are valid only if the vertical range of the organism has been encompassed. Studies on the vertical distribution of fish larvae have shown that rockfish larvae occur in the upper mixed layer and in the upper portion of the thermocline, but seldom deeper than this (Ahlstrom, 1959). Seventeen vertical distribution series containing *Sebastodes* larvae gave the following average depth distribution of the larvae:–

Depth of stratum (m)	Average weighted percentage in each stratum %
0–23	14·5
24–48	41·2
49–64	24·7
65–88	16·1
89–122	3·5
Below 122 m	0

Inasmuch as the standard plankton hauls sample a wider depth stratum than rockfish larvae are known to occupy, it is a safe assumption that their vertical range is routinely encompassed.

Sebastodes larvae

Scorpaenid fishes in the eastern North Pacific are given the common name of rockfish. The family Scorpaenidae is the largest family, in number of species, in the area that is being surveyed on cruises of the CCOFI. This region, which includes the waters off California and Baja California (and the Gulf of California), has approximately 61 species of scorpaenid fishes belonging to 5 genera: *Sebastodes, Sebastolobus, Scorpaena, Scorpaenodes,* and *Pontinus. Sebastodes,* by far the largest genus, has its centre of distribution off California. Forty-nine of the approximately 59 species of *Sebastodes* that are known to occur in the eastern North Pacific occur off California (Phillips, 1957). The southern limit of the distribution of the genus is in the vicinity of Magdalena Bay, Baja California. Two species apparently are endemic to the Gulf of California.

The genus *Sebastolobus,* with only two species in the eastern Pacific, interestingly enough, nearly encompasses the latitudinal distribution of the genus *Sebastodes*: Cape San Lucas, Baja California, to the Bering Sea. The other three genera are subtropical or tropical in distribution. There are about 10 species assigned to these genera in the eastern North Pacific. Eight occur off Baja California or in the Gulf of California, and only one, *Scorpaena guttata,* occurs as far north as southern California.

Scorpaenid larvae are readily distinguishable from those of other fish families. Their most characteristic feature is the paired parietal ridges on the back of the head, which terminate in spines. These first develop on larvae of 4 to 5 mm in length, and increase in prominence during the larval period. Each ridge ends in a single spine in *Sebastodes,* in a bifurcate spine in *Sebastolobus.*

Larger *Sebastodes* larvae can be distinguished from other scorpaenid larvae on the basis of meristics. Species of *Sebastodes* characteristically have 13 dorsal

Table 2

Relative abundance (standard haul totals) of the 12 most common kinds of fish larvae during 1957 in the area surveyed by CCOFI, compared with their contributions in 1955 and 1956

	1955			1956			1957		
	Number	%	Rank	Number	%	Rank	Number	%	Rank
Engraulis mordax	140,183	39·0	1	134,931	33·1	1	146,631	29·7	1
Merluccius productus	60,090	16·7	2	89,857	22·0	2	78,283	15·9	2
Vinciguerria lucetia	12,654	3·5	9	9,832	2·4	9	55,114	11·2	3
Sebastodes spp.	29,341	8·2	3	29,144	7·1	3	36,473	7·4	4
Leuroglossus stilbius	15,111	4·2	5	18,620	4·6	5	29,506	6·0	5
Trachurus symmetricus	13,246	3·7	7	8,027	2·0	10	20,006	4·0	6
Lampanyctus leucopsarus	7,454	2·1	10	15,125	3·7	7	16,808	3·4	7
Lampanyctus mexicanus	13,165	3·7	8	10,802	2·6	8	16,207	3·3	8
Citharichthys spp.	20,411	5·7	4	23,635	5·8	4	15,813	3·2	9
Diogenichthys laternatus	4,771	1·3	11	3,158	0·8	13	11,603	2·3	10
Sardinops caerulea	14,121	3·9	6	15,523	3·8	6	9,833	2·0	11
Bathylagus wesethi	3,245	0·9	12	2,146	0·5	17	6,347	1·3	12
All others	25,363	7·1		47,340	11·6		50,925	10·3	
Total	359,155	100·0		408,140	100·0		493,549	100·0	

spines. This character alone is sufficient to separate *Sebastodes* from other rockfishes in the eastern North Pacific, with the exception of *Scorpaenodes xyris*. There are but 12 dorsal spines in the species of *Scorpaena* and *Pontinus* that occur in the CCOFI area, 15 to 17 in *Sebastolobus*. The simplest character for separating *Scorpaenodes xyris* from *Sebastodes* is the number of dorsal rays: *S. xyris* almost always has 10, while species of *Sebastodes* have 12 or more.

All members of the genus *Sebastodes* give birth to young, i.e., are ovoviviparous. This mode of reproduction may be limited to this genus in the eastern Pacific, since both *Scorpaena* and *Sebastolobus* are known to lay their eggs in large masses. It is unlikely that any scorpaenid spawns free pelagic eggs – hence scorpaenid eggs are not a constituent of the plankton hauls.

The most recent three years for which data are complete have been chosen – 1955 through 1957 – to illustrate the distribution and abundance of *Sebastodes* larvae in the area being surveyed by the CCOFI. The basic data for these years are given in Ahlstrom and Kramer, 1957; Ahlstrom, 1958; and Ahlstrom, 1959. The abundance of larvae of *Sebastodes* are compared with those of other pelagic marine fishes in Table 2. In 1955, *Sebastodes* larvae constituted 8·2 % of the larvae obtained on the survey cruises; in 1956, 7·1 %; and in 1957, 7·4 %. In 1955 and 1956, *Sebastodes* larvae were exceeded in abundance by only two kinds of larvae: northern anchovy (*Engraulis mordax*) and Pacific hake (*Merluccius productus*). In 1957, *Sebastodes* larvae ranked 4th, behind northern anchovy, hake, and *Vinciguerria*.

Distributions of *Sebastodes* larvae during the three years, 1955–1957, are illustrated in Figures 2 to 4. The distributions are essentially similar in that the larvae are widespread throughout the survey area. The values shown on the charts are the average numbers of larvae obtained per haul at each station. This is a measure of relative abundance only.

The southern extent of the distribution of *Sebastodes* larvae has been delimited by these surveys, since this genus occurs only as far south as Magdalena Bay. The offshore distribution appears to be delimited off much of Baja California, but not off California, since *Sebastodes* larvae were obtained at some outer stations of the survey grid. Outer stations in the survey pattern off southern California are approximately 250 miles offshore.

The northern extent of the distribution is in no wise delimited by the CCOFI survey cruises. *Sebastodes* larvae are known to be common even in the Gulf of Alaska. There is evidence, however, that their centre of abundance is off southern California.

Ocurrences and abundance of rockfish larvae in different parts of the survey pattern are summarized in Table 3. The average number of larvae per haul for each area is given in the last column of the table. The largest value in all three years occurred in the area off southern California (station lines 80–93), although in one season, 1955, the average number per haul off central California (station lines 60–77) was nearly as large. Abundance off southern California was very similar in 1955 and 1956, but there was a marked increase in the average number of rockfish larvae obtained per haul in 1957. It is interesting to note that the frequency of their occurrences in this area has remained quite constant during these three years: between 62·7 % and 63·9 % of the collections made off southern California each year have contained *Sebastodes* larvae.

Seasonal distribution of *Sebastodes* larvae for the three years are summarized in Table 4. Because of the varying number of stations occupied per month, the values are given in terms of the average number of

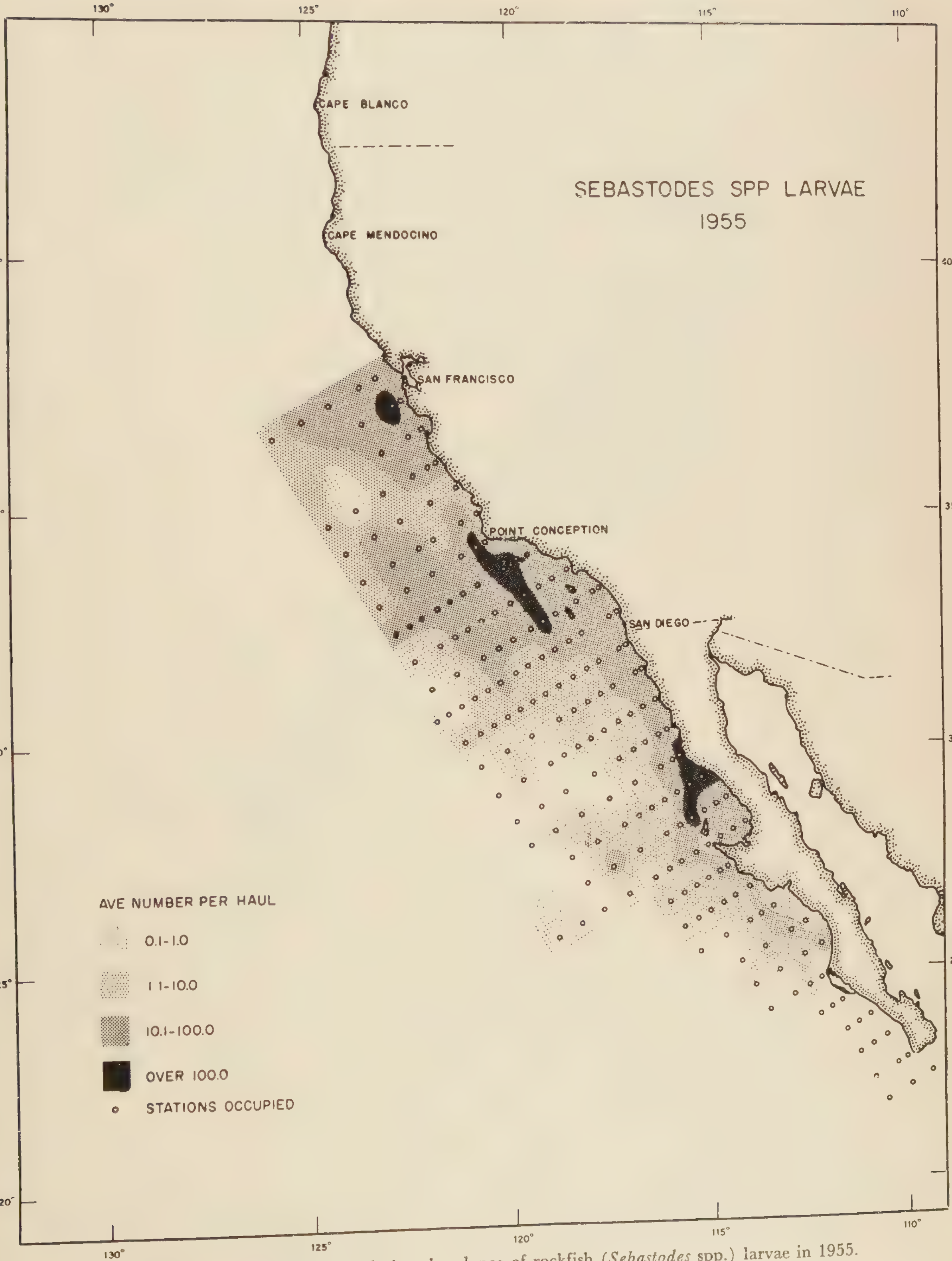

130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE BLANCO
CAPE MENDOCINO
SEBASTODES SPP LARVAE
1955
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
AVE NUMBER PER HAUL
0.1-1.0
1.1-10.0
10.1-100.0
OVER 100.0
STATIONS OCCUPIED

Figure 2. Distribution and relative abundance of rockfish (*Sebastodes* spp.) larvae in 1955.

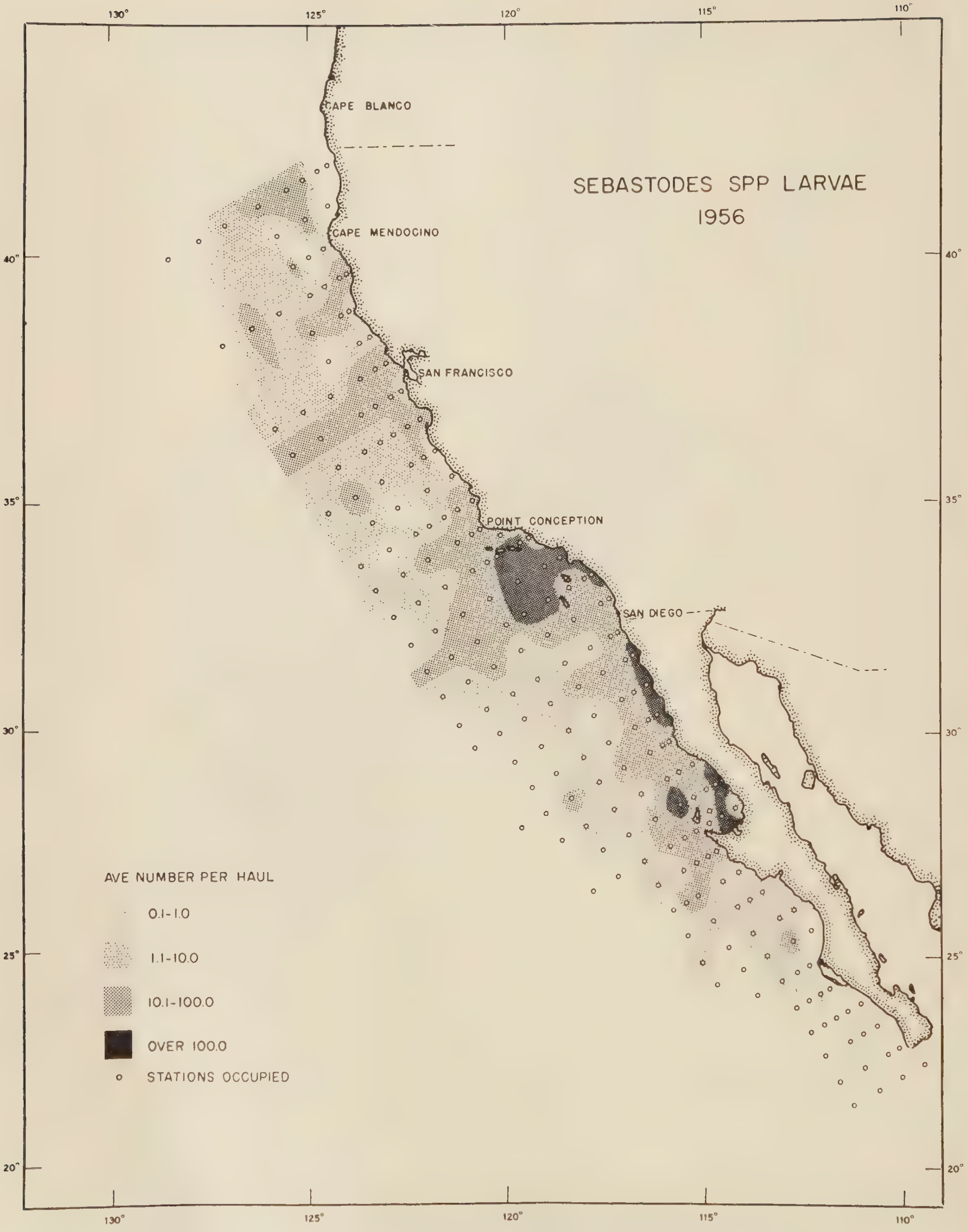

SEBASTODES SPP LARVAE
1956
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
AVE NUMBER PER HAUL
0.1-1.0
1.1-10.0
10.1-100.0
OVER 100.0
STATIONS OCCUPIED
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°

Figure 3. Distribution and relative abundance of rockfish (*Sebastodes* spp.) larvae in 1956.

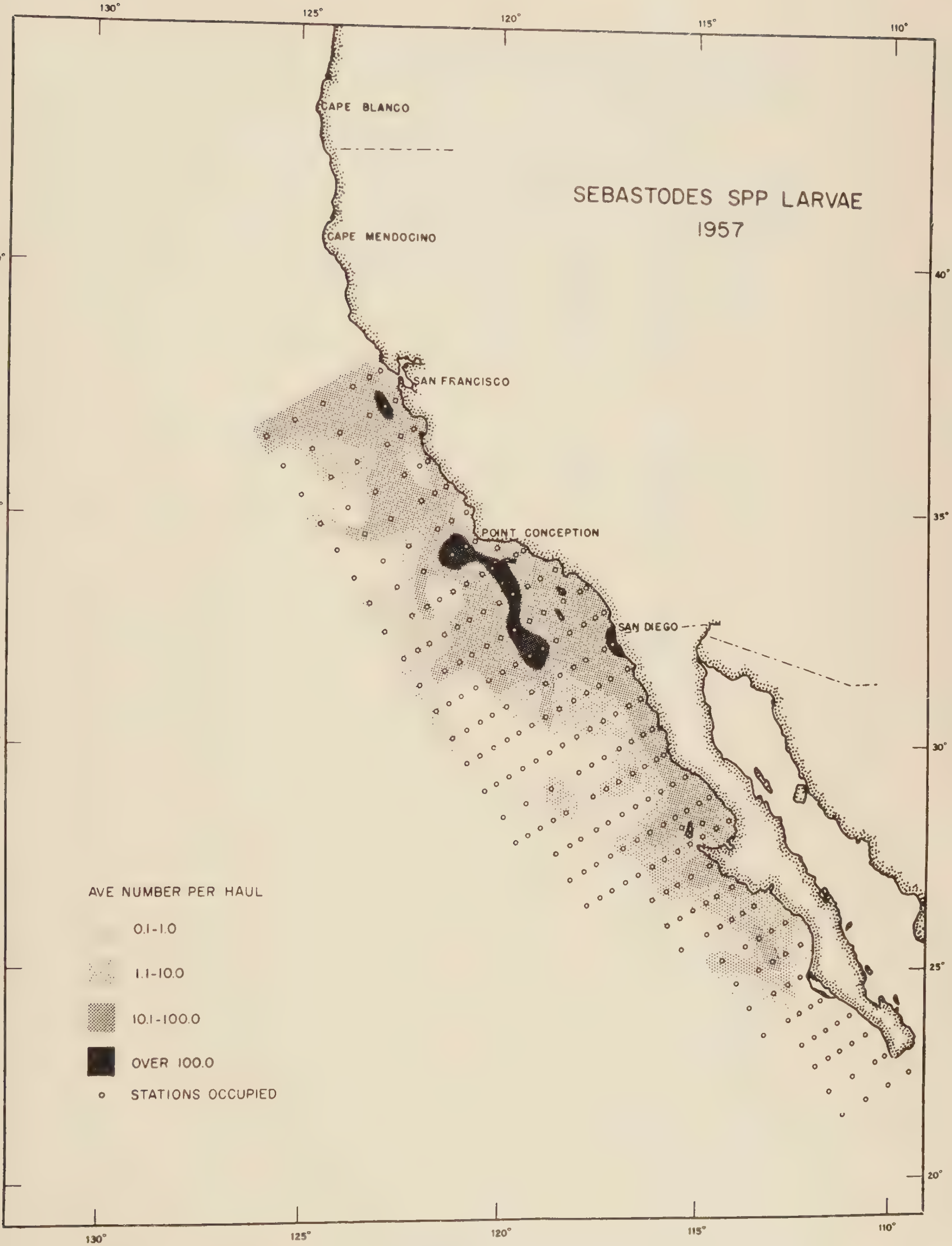

130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE BLANCO
CAPE MENDOCINO
SEBASTODES SPP LARVAE
1957
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
AVE NUMBER PER HAUL
0.1-1.0
1.1-10.0
10.1-100.0
OVER 100.0
STATIONS OCCUPIED

Figure 4. Distribution and relative abundance of rockfish (*Sebastodes* spp.) larvae in 1957.

Table 3
Relative abundance of *Sebastodes* larvae in various parts of the area surveyed on cruises of the CCOFI, 1955—1957

Station lines	Number of samples	Occurrences of *Sebastodes* larvae	% occurrences	Total number of larvae	% taken in each area	Average number per haul
1955						
60–77	86	58	67·4	2,893	9·9	33·6
80–93	391	250	63·9	14,571	49·6	37·2
97–107	290	133	45·9	3,721	12·7	12·8
110–120	334	133	39·8	6,336	21·6	19·0
123–137	202	75	37·1	1,796	6·1	8·9
140–157	72	3	4·2	24	0·1	0·3
Total	1,375	652	47·4	29,341	100·0	20·6
1956						
40–57	54	24	44·4	411	1·4	7·6
60–77	112	59	52·6	1,570	5·4	14·0
80–93	393	247	62·9	14,674	50·4	37·3
97–107	274	97	35·4	4,703	16·1	17·2
110–120	308	112	36·4	6,306	21·6	20·5
123–137	180	65	36·1	1,424	4·9	7·9
140–157	76	10	13·2	56	0·2	0·7
Total	1,397	614	43·9	29,144	100·0	20·8
1957						
60–77	101	68	67·3	3,170	8·7	31·2
80–93	364	228	62·7	23,163	63·5	63·5
97–107	287	90	31·4	3,779	10·4	13·2
110–120	360	109	30·3	4,878	13·4	13·5
123–137	267	63	23·6	1,466	4·0	5·5
140–157	114	3	2·6	17	<0·1	0·1
Total	1,493	561	37·6	36,473	100·0	24·4

larvae per station (i.e., haul). The picture is a fairly consistent one. The largest number of *Sebastodes* larvae per haul usually is obtained in February, and higher than average numbers are taken from December through April. Low numbers per haul prevail during the months of June through October. Coverage of the survey area was restricted during most cruises made between August and December, hence values for this portion of the year are not as reliable as during January through July. Even allowing for this, it should not basically alter the seasonal pattern as outlined above. Most rockfish larvae are released during the winter and spring months. Inasmuch as a number of species of *Sebastodes* are included in the collections, most of them must have a similar seasonal pattern of reproductive activity.

References

Ahlstrom, E. H., 1958. "Sardine eggs and larvae and other fish larvae, Pacific coast, 1956." Spec. Sci. Rep. Fish. U.S. Fish. Wildl. Serv., No. 251.

Ahlstrom, E. H., 1959. "Sardine eggs and larvae and other fish larvae, Pacific coast, 1957." Spec. Sci. Rep. Fish. U.S. Fish. Wildl. Serv., No. 328.

Ahlstrom, E. H., 1959. "Vertical distribution of pelagic fish eggs and larvae off California and Baja California." Fish. Bull. U.S., *60* (161): 107–46.

Ahlstrom, E. H., & Kramer, D., 1957. "Sardine eggs and larvae and other fish larvae, Pacific coast, 1955." Spec. Sci. Rep. Fish. U.S. Fish. Wildl. Serv., No. 224.

Phillips, J. B., 1957. "A review of the rockfishes of California (Family Scorpaenidae)." Fish. Bull. Sacramento, No. 104.

Phillips, J. B., 1958. "Rockfish Review." In: "The Marine Fish Catch of California for the Years 1955 and 1956." Fish. Bull., Sacramento, No. 105: 7–25.

Table 4
Seasonal (monthly) abundance of *Sebastodes* larvae, 1955—1957

	1955			1956			1957		
	Number of stations occupied	Number of larvae	Average per station	Number of stations occupied	Number of larvae	Average per station	Number of stations occupied	Number of larvae	Average per station
January	112	6,281	56·1	110	4,293	39·0	57	1,010	17·1
February	117	6,206	53·0	130	7,717	59·4	142	11,001	77·5
March	142	3,653	25·7	134	6,404	47·8	124	6,585	53·1
April	134	3,533	26·3	178	2,887	16·2	207	7,225	34·9
May	184	1,895	10·3	239	2,286	9·5	205	4,819	23·5
June	189	1,732	9·2	209	1,584	7·6	253	2,742	10·8
July	196	2,676	13·7	201	1,489	7·4	217	1,383	6·4
August		Norpac		36	397	11·0	41	47	1·2
September	43	313	7·3	36	0	0	37	28	0·8
October	109	461	4·2	42	317	7·5	143	231	1·6
November	43	1,897	44·1	40	358	9·0	44	586	13·3
December	106	694	6·5	42	1,412	33·6	23	816	35·5
Total	1,375	29,341	21·3	1,397	29,144	20·9	1,493	36,473	24·4

A/S L. Ihrich, Copenhagen

2

Use of 3-Trifluormethyl-4-nitrophenol as a Selective Sea Lamprey Larvicide

reat Lakes Fishery Commission

CHNICAL REPORT No. 1
1961

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

A report describing the Commission actions and the progress of the sea lamprey program, carried out by contracts with the United States Bureau of Commercial Fisheries and the Fisheries Research Board of Canada, is published annually. Included in this report is a summary of the work of federal, state and provincial agencies co-operating in a program to restore lake trout. There is also an outline of the fishery investigations under way in the Great Lakes. However, the need for a more detailed presentation of certain information has led to the establishment of a Technical Report Series, of which the following report on the use of chemicals to control sea lamprey is the first.

COMMISSIONERS

CANADA	UNITED STATES
A. O. Blackhurst	D. L. McKernan
J. R. Dymond	Claude Ver Duin
A. L. Pritchard	Lester P. Voigt

1319 N. University Ave.
Ann Arbor, Michigan

USE OF 3-TRIFLUORMETHYL-4-NITROPHENOL AS A SELECTIVE SEA LAMPREY LARVICIDE

By

VERNON C. APPLEGATE, JOHN H. HOWELL, JAMES W. MOFFETT

United States Bureau of Commercial Fisheries

B. G. H. JOHNSON

Fisheries Research Board of Canada

and

MANNING A. SMITH

Dept. of Chemistry, Bucknell University

1961

CONTENTS

INTRODUCTION 3

3-TRIFLUORMETHYL-4-NITROPHENOL (TFM) . . 4

BIOASSAY METHODS 7

BIOASSAY RESULTS 8

RACEWAY TEST METHODS 15

RACEWAY TEST RESULTS 16

EXPERIMENTAL STREAM TREATMENTS 22

- Treatment of the Mosquito River . . . 23
- Treatment of the Silver River 27
- Treatment of the Pancake River and its tributary Gimlet Creek . . . 29

ACKNOWLEDGMENTS 33

LITERATURE CITED 33

USE OF 3-TRIFLUORMETHYL-4-NITROPHENOL AS A SELECTIVE SEA LAMPREY LARVICIDE

The recent discovery of a group of chemical compounds that are significantly more toxic to sea lampreys than to other aquatic organisms offers promise of an early and effective control of this pest. The sea lamprey has all but destroyed the lake trout populations of Lakes Huron and Michigan. In Lake Superior, production of the lake trout fishery has declined to record low levels. Only a rapid and drastic reduction in sea lamprey predation can save the lake trout population there. Other species of food and game fishes have suffered severe decreases from persistent attack by the lamprey.

The sea lamprey spends only a small portion of its life as a parasite in the Great Lakes. The fully grown and sexually mature adults migrate into streams to spawn and thereafter die. The eggs hatch in a week to 10 days and the larvae remain in the stream bottom for 5 years or longer before metamorphosis into the adult form. Following this transformation the young lampreys migrate downstream to the lakes to begin their parasitic existence. The life cycle of the sea lamprey has been described in detail elsewhere (Applegate 1950; Applegate and Moffett 1955).

Control of the adult lampreys distributed throughout a body of open water as large as one of the Great Lakes, by known and available techniques, is not feasible. Fortunately, this pest can be attacked effectively at those stages in its life cycle when it is concentrated in restricted areas. Various devices have been developed which prevent spawning by blocking the streams below the spawning grounds. Electrical weirs, that repel or destroy the lampreys, have been used (Applegate, Smith, and Nielsen 1952; Erkkila, Smith, and McLain 1956). A serious shortcoming of this control method is the time required to achieve the desired effect. Even though the adults have been destroyed before spawning, 5 or more generations of larval lampreys are already in the stream—enough to provide an annual supply of parasitic adults for an equal period of time.

Almost all the larvae of the sea lamprey live in the spawning streams. Treatment of these streams with selectively toxic chemicals that kill the larvae provides immediate reduction of all generations in the population before they become parasites. Control of the species can thus be achieved without a delay of several years.

Applegate, Howell, and Smith (1958) reported the differential toxic effects among larval lampreys and fishes of 6 mononitrophenols containing halogens. Subsequently, 4 additional compounds in this chemical group were discovered that display similar selectively toxic properties. All of these halogenated mononitrophenols have certain characteristics in common. They have from 1 to 3 halogens substituted in the ring, or in an aliphatic radical attached to the ring. Only one nitro group is present. They differ in the number and type of halogen atoms (F, Cl, or Br) attached to the phenol molecule and in the positions of the nitro and halo groups relative to the hydroxyl group. The 10 selectively toxic nitrophenols are:

2-Bromo-4-nitrophenol
3-Bromo-4-nitrophenol
2-Chloro-4-nitrophenol
5-Chloro-2-nitrophenol
3-Fluoro-4-nitrophenol
2, 5-Dichloro-4-nitrophenol
3, 4, 6-Trichloro-2-nitrophenol
3-Trifluormethyl-2-nitrophenol
2-Trifluormethyl-4-nitrophenol
3-Trifluormethyl-4-nitrophenol

Although all of these compounds are more toxic to lampreys than to most other aquatic organisms, certain of them are more desirable for practical applications because of their physical and chemical properties, ease of handling in the field, effectiveness at low concentrations, and cost. Of all the compounds, 3-trifluormethyl-4-nitrophenol met these requirements most closely and hence was selected at an early date for development for field use. This report is concerned with the laboratory tests, field trials, and early operational treatments that were undertaken with this compound.

3-TRIFLUORMETHYL-4-NITROPHENOL (TFM)

TFM is a crystalline solid at room temperature, yellow to orange in color in its pure form, and light brown in technical-grade preparations. It is sparingly soluble in water (0.498 g. TFM/100 g. H_20 at 24.5° C.) but highly soluble in most organic solvents. Aqueous solutions of TFM are acidic ($pK - 6.07 \pm 0.03$) and form salts, called phenolates, in the presence of alkalis. Phenolates of the alkali metals are weak bases. The free phenol is colorless in acid solution but deep yellow in base solution. The compound is highly stable and resistant to biochemical attack. It is not detoxified by any known natural process.

TFM is selectively toxic among larval lampreys and fishes not only in the form of its free phenol but also as its sodium salt. Indeed, the two forms of the phenol appear to have nearly identical toxic properties (Applegate, Howell, and Smith 1958). The solubility of the sodium phenolate in water is much greater than that of the free phenol. Since a larvicide is best applied in the field as a water-miscible liquid formulation, only the phenolates are practical because their greater solubilities permit the preparation of more highly concentrated stock solutions. All laboratory and field experiments reported here were conducted with various formulations of the sodium salt of TFM.

Subsequent to these experiments we found that certain mixed amine salts of TFM are as effective in their biological properties as the sodium salts. The amine salts have more desirable physical properties than do the sodium salts, permitting commercial preparations of greater stock strength with better stability of the solutions when stored at low temperatures. Commercial formulations of the amine salts will be used extensively in stream treatments in the future.

All laboratory tests were conducted with a formulation of the sodium salt of TFM prepared from a purified sample of the compound (a commercial, technical-grade sample recrystallized from benzene-petroleum ether, m.p. 75°–76° C.). Dimethyl formamide and water were used as solvents. A commercial, technical-grade preparation (91 percent pure) was used in raceway (simulated stream) tests of the compound. This material was converted to its sodium salt and formulated as an aqueous solution containing 30 percent by weight of the active ingredient. A commercial formulation of the sodium salt of TFM called Lamprecid 2770[1] containing 15 percent by weight of the active ingredient was utilized in all experimental stream treatments reported here.

---

[1] Registered Trademark of Hostachem Corp., a division of Farbewerke Hoechst AG.

Constant temperature baths utilized in conducting bioassay tests. The four independantly controlled baths shown can hold 68 ten-liter test jars.

Simulated stream test of TFM in a running water raceway at the Hammond Bay Laboratory. Cylindrical screen cages contain either larval lampreys or small test fishes.

BIOASSAY METHODS

Laboratory facilities and equipment were similar to those described by Applegate, Howell, Hall, and Smith (1957). Animals were placed in 10-liter glass battery jars (10-inch diameter), each containing 6 liters of test solution. The suitability of this test volume was determined experimentally. The test jars were aerated by means of standard stone air-breakers. Oxygen levels in the jars during tests were maintained at near-saturation. Temperatures were held constant by immersion of the test jars in a specially constructed water bath.

Test animals were larvae of the sea lamprey (*Petromyzon marinus*) and fingerling rainbow trout (*Salmo gairdneri*). Lamprey larvae ranged from 3.5 to 5.0 inches and rainbow trout from 4.5 to 5.5 inches in total length. All larvae were collected from a restricted area of the Ocqueoc River, Presque Isle County, Michigan. The rainbow trout were obtained as a single lot of fish from a hatchery of the Michigan Department of Conservation.

In the typical test, 3 specimens of either larval lampreys or rainbow trout were placed in each test container. After the animals were tempered and acclimated to the test temperature, appropriate amounts of TFM in aqueous solutions were added to produce the desired concentrations. Sixteen simultaneous replications were run with a total of 48 individuals of each species at each concentration. In certain assays conducted with test waters of varying characteristics from a group of tributaries of the upper Great Lakes, 2 specimens of each test species were placed in each jar and only 8 replications were made at each concentration. This reduction in test animals and replications was dictated by the limited volume of test water that could be transported over long distances.

Dilution waters were obtained from several sources depending on the purpose of the experiments. Tests to determine the biological activity of TFM at 3 temperature levels were made with a single lot of water taken from Hammond Bay of Lake Huron. This water was stored under semi-refrigerated conditions in a concrete tank which had an inert coating on its interior walls. The physical and chemical characteristics of the water did not change significantly during storage and use. Average values during the period were: oxygen, 13.0 ppm; CO_2, 2.2 ppm; methyl-orange alkalinity, 109 ppm; phenolphthalein alkalinity, 0.0 ppm; pH, 7.7; conductivity, 182.3 *m*Mhos/18° C. The biological activity of TFM in waters of differing physical and chemical properties was tested in dilution waters collected from a series of widely separated tributaries of Lakes Huron, Michigan, and Superior, that were known from preliminary experiments to differ broadly in water quality. The properties of these waters are indicated elsewhere in this report.

Physical and chemical analyses of dilution waters were made immediately before their use in all tests. Dissolved oxygen was checked frequently during the tests to insure an adequate concentration. All physical and chemical determinations were made according to the procedures set forth in the ninth edition of "Standard Methods for the Examination of Water and Sewage." TFM concentrations in all test containers were checked colorimetrically by the method described in Smith, Applegate, and Johnson (1960).

The laboratory tests were conducted for a 24-hour period. The responses of the test animals were observed frequently, usually at 30-minute intervals. In experiments where the test animals were slow to die, observations were made at 1-hour intervals. Arithmetic dosage intervals were employed in all laboratory work. These data were sufficiently descriptive to permit rapid development of techniques for the application of TFM in streams.

BIOASSAY RESULTS

Earlier investigations established that TFM is acutely toxic to larval lampreys at low concentrations and that at these concentrations it is non-toxic to other fishes inhabiting the same waters. The chemical also destroyed the larvae in a relatively short time. It exhibited the most definitive action on larvae and functioned at the lowest concentration of any of the nitrophenols tested. It was further established that the differential toxicity displayed by TFM covered a sufficiently broad range of concentrations to permit its regulated application in streams to destroy lamprey larvae without concurrent damage to other fish (Applegate, Howell, and Smith 1958). To extend these preliminary findings, experiments were conducted in the laboratory to determine the effect of certain physical and chemical properties of natural waters upon the biological activity of TFM.

The effect of water temperature upon the toxicity of the chemical was explored by performing tests at 35°, 45°, and 55° F. The results indicated very little difference in the activity of TFM at these 3 temperatures. The minimum lethal dose for larval lampreys (concentration killing 100 percent of the test larvae within 24 hours) was 2.0 ppm at all three temperatures (Table 1, Figure 1). The velocity of death of the larvae slowed, however, as the temperature was lowered (Table 2). A small reduction was detected in the toxicity of TFM to rainbow trout as water temperature declined (Table 1, Figure 1). Maximum allowable dosages (concentration killing approximately 25 percent of the rainbow trout within 24 hours) were 8.9 ppm at 55° F., 9.3 ppm at 45° F., and 9.7 ppm at 35° F. These values were derived from the curves in Figure 1. The velocity of death of the rainbow trout was also slowed by lowered temperatures (Table 3).

TABLE 1.—Mortalities of larval sea lampreys and rainbow trout exposed to various concentrations of the sodium salt of 3-trifluormethyl-4-nitrophenol at water temperatures of 35°, 45°, and 55°F.

[Test period—24 hours]

Concentration of TFM (ppm)	Percentage mortality					
	at 35°F.		at 45°F.		at 55°F.	
	Larval sea lampreys	Rainbow trout	Larval sea lampreys	Rainbow trout	Larval sea lampreys	Rainbow trout
0.75	0.0	. .	2.1	. .	0.0	. .
1.0	4.2	. .	8.3	. .	4.2	. .
1.25	25.0	. .	29.2	. .	27.1	. .
1.5	45.8	. .	47.9	. .	47.9	. .
1.75	89.6	. .	83.3	. .	83.3	. .
2.0	100.0	. .	100.0	. .	100.0	. .
3.0	100.0	. .	100.0	. .	100.0	. .
4.0	. .	. .	. .	. .	. .	. .
5.0	. .	. .	. .	. .	. .	. .
6.0	. .	. .	. .	. .	. .	. .
7.0	. .	. .	. .	. .	. .	0.0
8.0	. .	0.0	. .	0.0	. .	12.5
9.0	. .	6.3	. .	18.8	. .	26.7
10.0	. .	31.2	. .	37.5	. .	43.8
11.0	. .	56.3	. .	62.5	. .	63.8
12.0	. .	75.0	. .	82.3	. .	87.5
13.0	. .	86.3	. .	100.0	. .	100.0
14.0	. .	100.0	. .	. .	. .	. .

TABLE 2.—Velocity of death of larval sea lampreys exposed to various concentrations of the sodium salt of 3-trifluormethyl-4-nitrophenol at water temperatures of 35°, 45°, and 55°F.

[Test period—24 hours]

Concentration of TFM (ppm)	35°F.				45°F.				55°F.			
	Percentage mortality	Time to death (hours)			Percentage mortality	Time to death (hours)			Percentage mortality	Time to death (hours)		
		Min.	Aver.	Max.		Min.	Aver.	Max.		Min.	Aver.	Max.
0.75	0.0	..	..	..	2.1	..	(21.0)	..	0.0	..	..	..
1.0	4.2	17.0	19.0	22.0	8.3	17.0	18.0	19.0	4.2	17.0	19.0	21.0
1.25	25.0	13.0	17.8	22.0	29.2	13.0	16.9	20.0	27.1	6.0	15.2	21.0
1.50	45.8	11.0	16.4	22.0	47.9	10.0	15.3	22.0	47.9	8.0	14.4	22.0
1.75	89.6	10.0	15.3	21.0	83.3	10.0	14.7	22.0	83.3	6.0	13.2	21.0
2.0	100.0	9.0	14.0	20.0	100.0	6.0	11.8	20.0	100.0	5.0	10.4	16.0
3.0	100.0	7.0	10.3	12.0	100.0	5.0	7.3	12.0	100.0	5.0	6.9	10.0
5.0	100.0	5.0	6.3	7.5	100.0	3.0	4.5	5.5	100.0	2.5	3.8	7.0
7.0	100.0	4.5	5.6	7.5	100.0	3.0	4.0	5.5	100.0	2.0	3.1	4.5
9.0	100.0	3.0	4.5	5.5	100.0	2.0	3.3	4.0	100.0	1.5	2.7	3.5
11.0	100.0	3.0	4.2	5.0	100.0	2.0	2.6	3.5	100.0	1.5	2.2	3.0

Table 3.—Velocity of death of rainbow trout fingerlings exposed to various concentrations of the sodium salt of 3-trifluormethyl-4-nitrophenol at water temperatures of 35°, 45°, and 55°F.

[Test period—24 hours]

Concentration of TFM (ppm)	35°F.				45°F.				55°F.			
	Percentage mortality	Time to death (hours)			Percentage mortality	Time to death (hours)			Percentage mortality	Time to death (hours)		
		Min.	Aver.	Max.		Min.	Aver.	Max.		Min.	Aver.	Max.
8	0.0	..	..	.	0.0	..	..	..	12.5	13.5	16.8	20.0
9	6.3	..	(9.5)	..	18.8	14.0	17.6	19.0	26.7	1.0	11.1	21.5
10	31.2	10.0	15.4	20.0	37.5	4.0	13.8	20.0	43.8	1.5	9.5	22.0
11	56.3	6.5	14.6	20.5	62.5	4.5	12.4	20.0	68.8	1.0	5.0	11.5
12	75.0	6.0	11.5	19.5	82.3	2.5	8.0	19.0	87.5	1.5	4.6	7.0
13	86.3	6.5	10.2	17.5	100.0	2.3	5.4	13.3	..	.	..	.
14	100.0	6.5	10.0	18.0	100.0	2.3	4.4	11.3		..	..	

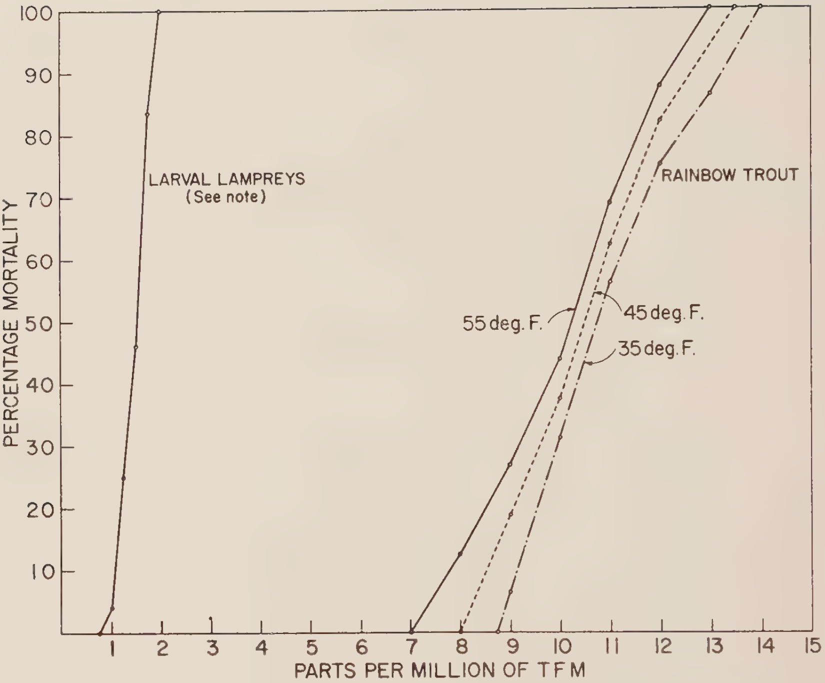


FIGURE 1.—Mortalities of sea lamprey larvae and rainbow trout fingerlings exposed to various concentrations of TFM at water temperatures of 35°, 45°, and 55°F.

NOTE: Responses of the larval lampreys are plotted only for a water temperature of 55°F. Mortalities of larvae at lower temperatures were so similar to those at 55°F. that separate curves could not be drawn (see Table 1).

The utility of the chemical as a selective larvicide is not impaired by low water temperatures. The differential toxic effects are, in fact, somewhat improved as water temperature drops to near freezing. As temperature is lowered from 55° to 35° F., mortalities caused by the compound among rainbow trout are slightly lessened whereas those among the larval lampreys remain essentially the same.

Certain characteristics of natural waters, other than temperature, influence the toxic effects of many chemicals upon aquatic organisms. Among these factors are pH, alkalinity, hardness, dissolved oxygen, and turbidity. Bioassays were conducted with dilution waters obtained from 16 tributaries of Lakes Huron, Michigan and Superior that varied widely in pH, conductivity, and alkalinity. Among them, they represented nearly the entire range of these characteristics found in streams infested with sea lamprey larvae. In these tests, temperature was held constant at 55° F.

The results of these bioassays are summarized in Table 4 where pertinent physical and chemical properties of the waters are also given. The responses of the test animals are reported in terms of minimum lethal dosages for lampreys and maximum allowable dosages for rainbow trout.

The toxicity of TFM is strongly influenced by water hardness and pH. The chemical is most effective in soft, acid waters where the minimum lethal concentrations were as low as 0.5 ppm. As pH, conductivity, and alkalinity of the waters increased, the dosage requirements of TFM to effect a 100-percent kill of larval lampreys increased. In the hardest and most alkaline waters tested, the minimum lethal concentration for the larvae was 8.0 ppm. The changes in the toxicity of TMF to rainbow trout were comparable. The differential toxic action of the compound was retained regardless of its level of activity in any given water, *i.e.*, the increases in the minimum lethal concentration for larval lampreys and in the maximum allowable dose for trout were roughly proportional. Treatment of any stream with TFM is not precluded because of variations in hardness and pH, but, quantities of TFM required for effective treatment may be considerably greater in hard, alkaline waters than in soft and acid waters.

No clear-cut relation could be demonstrated between the biological activity of TFM and these properties of the water. Measurements of pH, alkalinity, and conductivity, which reflect in some measure the ionic composition of the natural waters, are only broadly correlated with the biological activity of TFM. It is presumed that the toxicity of TFM is affected by a combination of ions present in the water; the most important probably are those of calcium and hydrogen. Prediction of the precise toxicity of TFM from analyses of stream water is not possible, however, at present.

The effects of dissolved oxygen on the toxicity of TFM to larval lampreys and fishes were not evaluated. Such information is not critical since concentrations of dissolved oxygen are relatively high in the great majority of streams inhabited by sea lamprey larvae. Neither has the effect of turbidity upon the toxicity of the compound been explored but results of several simulated stream trials and actual stream treatments in turbid water gave no indication at all that turbidity affected the toxicity of TFM.

The biological activity of the halo-mononitrophenols in waters of the upper Great Lakes varies seasonally. TFM is most effective during late fall, winter, and early spring. Its toxicity diminishes during late spring and is at a minimum in July and August. The compound then becomes more toxic again during the early fall. The degree of seasonal change in toxicity varies according to location around the three upper lakes; in some areas it is negligible but in others the change is pronounced. The decline in biological activity of TFM in summer in

TABLE 4.—Variation in the biological activity of the sodium salt of 3-trifluormethyl-4-nitrophenol in waters of differing physical and chemical characteristics.

[Tests conducted for a 24-hour period at a water temperature of 55°F.]

Source of test water	Minimum lethal dose of TFM[1] (ppm)	Maximum allowable dose of TFM[2] (ppm)	Properties of test water				
			Conductivity (*m*Mhos/18° C.)	CO_2 (ppm)	phth alk. (ppm)	M. O. alk. (ppm)	pH
Boyne River, Ontario	0.5	2.25	36.6	2.7	0.0	17.0	6.8
Goulais River, Ontario	0.5	2.5	52.6	3.5	0.0	28.0	6.9
Big Carp River, Ontario	0.5	2.75	64.2	4.5	0.0	28.0	6.7
Stokely River, Ontario	0.75	2.75	62.4	3.6	0.0	37.0	7.0
Bad River, Wisconsin	1.0	4.5	79.7	2.5	0.0	47.0	7.3
Brule River, Wisconsin	1.0	4.5	96.9	2.3	0.0	57.0	7.4
Two Hearted River, Michigan	1.5	6.0	83.7	3.6	0.0	70.0	7.3
Gravel River, Ontario	1.5	4.75	114.2	4.2	0.0	83.0	7.3
White River, Wisconsin	1.5	5.75	139.0	1.8	0.0	90.0	7.7
Sucker River, Michigan	2.0	8.5	109.5	1.6	0.0	68.0	7.6
No. Br., Fish Creek, Wisconsin	2.0	8.0	132.1	2.1	0.0	83.0	7.6
Pere Marquette River, Michigan	3.0	9.0	297.4	3.8	tr.	156.0	7.6
Jordan River, Michigan	5.0	17.0	307.1	1.4	0.0	179.0	8.1
Nottawasaga River, Ontario	5.0	>15.0	381.4	1.8	8.0	255.0	8.1
Pipestone Creek, Michigan	6.0	>17.0	408.5	2.1	0.0	205.0	8.0
Kewaunee River, Wisconsin	8.0	>29.0	380.8	1.4	5.0	217.0	8.1

[1] Minimum dose required to kill 100 percent of the larval lampreys.

[2] Dose required to kill 25 ± percent of the rainbow trout.

streams of certain areas is sufficient to render impractical the treatment of these watersheds in this season because of the high cost of the chemicals required to give the dosage levels needed to kill the larvae. For economic reasons, therefore, nearly all stream treatments are undertaken during the fall, winter, and spring. A thorough study of this phenomenon and its possible causes is presently underway.

The physiological effects of TFM upon test lampreys have not been completely explored. This chemical causes an excoriation of the respiratory epithelium accompanied by rupture of this tissue and enlargement of the blood vessels supplying it. Severe hemorrhaging from the respiratory capillaries often fills the gill pouches with blood. The compound is also hypotensive in its effect upon the larvae. Blood vessels become dilated, particularly the large posterior cardinal veins which lie on the dorsal wall of the coelom. These vessels, as well as other elements of the venous system, become greatly engorged with blood. These observations suggest that the lampreys suffer a general circulatory collapse aggravated by suffocation due to the presence of excessive mucus and blood in the gill pouches. Lamprey larvae appear first to be irritated, then to be narcotized, by the toxicant. Respiration becomes irregular and responses to stimuli weaken.

Rainbow trout exposed to high concentrations of TFM exhibit different symptoms. Irritability increases to the time of death. The fish exhibit symptoms of anoxia such as surfacing movements and distended gill covers. The gills give no evidences of hemorrhaging but instead become coated with coagulated mucus. This coating doubtless contributes to the suffocation of the fish.

RACEWAY TEST METHODS

Experiments were made with TFM in a running-water raceway to provide an intermediate stage of testing of the chemical which would approach natural stream conditions more closely than the conventional bioassay tests. These trials also yielded information on the action of TFM under continuous water flow which required the regulated metering of the chemical, as an aqueous solution of its sodium salt, into the "stream."

The raceways are concrete troughs, 65 feet long, 6 feet wide and 30 inches deep. Water from Lake Huron is delivered to the head of the race through a surge tank which stabilizes the flow. The volume of water discharged into the experimental "stream" is measured through a "V" weir.

An artificial stream bed was constructed on the floor of the raceway for each test with materials taken from the beds of local rivers. The topography of this artificial stream provided a small mixing pool at the head of the race, followed by a shallow gravel riffle, and then a pool about 18 inches deep. A second shallow-water area, usually of sandy materials, was located about midway along the race. Below this point was another silt-bottomed pool. At the foot of the latter pool, a final, shallow riffle was created of sandy or silt materials. Water dropped into a waste flume from the foot of this last riffle.

Test specimens were placed in this artificial stream sufficiently in advance of a treatment to allow them to become adjusted to it. Larger fishes such as the trouts, bullheads, adult suckers, large rock bass, and mature sea lampreys moved unrestricted within the 65-foot-long test area. Smaller fishes were placed in cylindrical screen cages at various points throughout the "stream." Larval lampreys were kept in similar screen cages set deeply enough into the bottom to permit the larvae to establish themselves in burrows. Restriction of the smaller fishes and the larval lampreys to these cages permitted more rapid and accurate determination of mortalities. About 15 species were employed in each test. These usually included sea lampreys (2 or more life-history stages), 3 trout species, miscellaneous "panfish," "rough fish," forage minnows, turtles, crawfish, and aquatic insects.

Each experimental treatment was conducted for 24 hours. The TFM was metered into the water by an electric-motor-driven, dual-piston fluid-proportioning device. This machine pumped from a concentrated stock solution and delivered the concentrate, diluted with flush water, to a perforated pipe located in the mixing pool at the head of the raceway. The concentration of the larvicide in the raceway was controlled by regulating the concentration of the stock solution and the feed rate of the proportioning equipment. The technique was essentially that planned for treatment of natural streams.

During a test, observations were made of all animals at intervals of 2 hours or less. Water temperatures were recorded at the head and foot of the raceway at 2-hour intervals. The fluid-proportioning device was checked at least hourly to assure that it was feeding at an accurate rate.

RACEWAY TEST RESULTS

Eight raceway or simulated stream tests were conducted, each at a different concentration of TFM. Test concentrations ranged from 1.5 to 13.0 ppm. Results obtained are summarized in Table 5. The common and scientific names of test animals used are listed in Table 6.

Under conditions that simulated treatment of a stream, the differential toxic effects of TFM among lampreys and rainbow trout were essentially the same as those displayed in bioassay tests. The mortality of larval lampreys was 100 percent at concentrations as low as 3.0 ppm. At 1.5 ppm, the next lower concentration tested, 91.5 percent of the larvae were killed. Rainbow trout were not affected by a 24-hour exposure to concentrations as high as 11.0 ppm.

TABLE 5.—Toxicity of an aqueous solution of the sodium salt of 3-Trifluormethyl-4-nitrophenol to sea lampreys (*Petromyzon marinus*), fishes, aquatic insects, crayfish, and turtles as determined by simulated stream tests in a running-water raceway.

[Tests at indicated concentrations were conducted for a 24-hour period at various water temperatures ranging from 45° to 55°F. Mean water temperatures extant during testing at each concentration are listed below.]

Concentration of TFM (ppm)	Mean water temperature (F.°)	Percentage mortality of test species (Number of specimens of each species utilized indicated parenthetically beneath each mortality datum; total number of test animals utilized 1,749.)																					
		Larval sea lampreys	Adult sea lampreys (mature upstream migrants)	Adult sea lampreys (recently transformed)	Rainbow trout	Brook trout	Brown trout	Rock bass	Sunfishes	Yellow perch	White suckers (adults)	White suckers (immature)	Bullheads	Common shiners	Lake chubs	Creek chubs	Longnose dace	Central mudminnows	Logperch	Mottled sculpins	Turtles	Crayfish	Caddisfly larvae
1.5	47.4	91.5 (153)	0.0 (5)	0.0 (9)	0.0 (10)	0.0 (10)	0.0 (10)	0.0 (1)	0.0 (5)	0.0 (6)	0.0 (5)	0.0 (6)	0.0 (8)	40.0 (5)	...	0.0 (1)	0.0 (7)	.....	0.0 (2)	.....			
3.0	45.9	100.0 (150)	100.0 (5)	100.0 (5)	0.0 (10)	0.0 (10)	0.0 (10)	...	0.0 (11)	0.0 (6)	0.0 (5)	0.0 (5)	0.0 (15)	0.0 (20)	0.0 (9)	0.0 (1)	0.0 (20)	.....	.....	0.0 (5)	0.0 (1)	0.0 (10)	
5.0	45.2	100.0 (149)	100.0 (5)	100.0 (10)	0.0 (10)	0.0 (10)	0.0 (10)	...	0.0 (12)	0.0 (8)	0.0 (5)	0.0 (2)	66.6 (12)	0.0 (10)	0.0 (5)	...	0.0 (5)	0.0 (5)	100.0 (1)	0.0 (10)	0.0 (2)	0.0 (15)	0.0 (3)
7.0	49.3	100.0 (150)	100.0 (5)	100.0 (10)	0.0 (10)	0.0 (10)	0.0 (10)	0.0 (3)	0.0 (8)	12.5 (8)	0.0 (5)	28.5 (7)	100.0 (11)	0.0 (16)	0.0 (3)	0.0 (1)	16.6 (6)	0.0 (5)	.....	0.0 (7)	...	0.0 (8)	0.0 (4)
9.0	54.4	100.0 (150)	100.0 (5)	.....	0.0 (10)	0.0 (10)	10.0 (10)	0.0 (1)	10.0 (10)	56.8 (12)	80.0 (5)	50.0 (10)	100.0 (11)	10.0 (10)	...	0.0 (1)	100.0 (10)	.....	100.0 (1)	.....	...	0.0 (3)	0.0 (4)
10.0	43.6	100.0 (149)	100.0 (5)	.....	0.0 (10)	0.0 (10)	10.0 (10)	0.0 (8)	100.0 (5)	100.0 (10)	80.0 (5)	100.0 (8)	93.3 (15)	100.0 (10)	...	...	100.0 (13)	100.0 (5)	100.0 (1)	100.0 (4)	0.0 (1)	0.0 (5)	0.0 (15)
11.0	45.9	.....	.....	.....	0.0 (10)	0.0 (10)	0.0 (10)	0.0 (5)	.....	.....	.....	.....	.....	.....	...	...	.....	.....	.....	.....	...	0.0 (5)	0.0 (10)
13.0	54.2	.....	.....	.....	80.0 (10)	0.0 (10)	50.0 (10)	...	.....	.....	.....	.....	.....	.....	...	...	.....	.....	.....	.....			

Table 6.—Common and scientific names of test animals used in toxicity tests of the sodium salt of 3-trifluormethyl-4-nitrophenol under simulated stream conditions.

Common name	Scientific name
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Bullheads	*Ictalurus melas, I. nebulosus*
Caddisfly larvae	Limnophilidae (primarily *Astenophylax* ssp.)
Central mudminnow	*Umbra limi*
Common shiner	*Notropis cornutus*
Crayfish	*Cambarus* ssp.
Creek chub	*Semotilus atromaculatus*
Lake chub	*Hybopsis plumbea*
Logperch	*Percina caprodes*
Longnose dace	*Rhinichthys cataractae*
Mottled sculpin	*Cottus bairdi*
Rainbow trout	*Salmo gairdneri*
Rock bass	*Ambloplites rupestris*
Sea lamprey	*Petromyzon marinus*
Sunfish	*Lepomis macrochirus, L. gibbosus*
Turtles	*Chrysemys picta, Chelydra serpentina*
White suckers	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

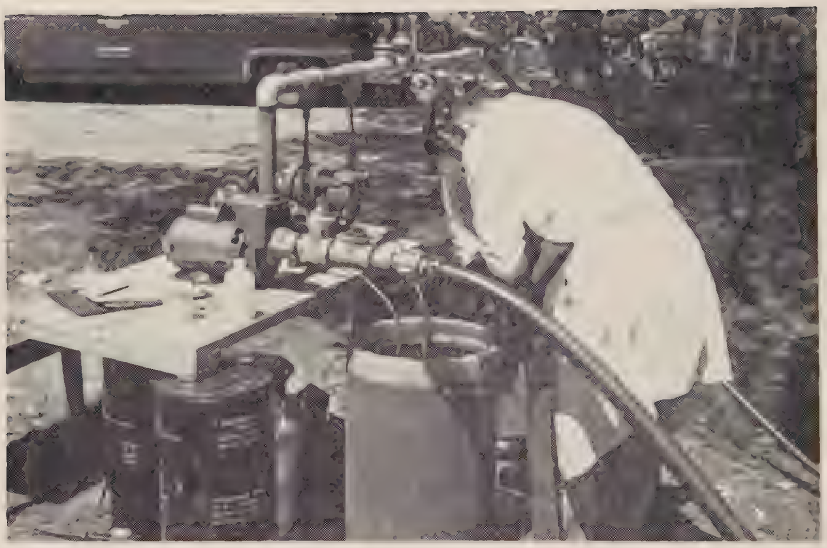
Particularly valuable was the finding that mature, adult sea lampreys (upstream migrants of the spawning run) and recently-transformed lampreys (downstream migrants) were also killed by TFM at concentrations as low as 3.0 ppm. Treatment of streams with TFM during the spring spawning run of mature adults or during the fall and winter downstream movement of recently-transformed individuals will destroy at least part of these migrant populations along with the populations of larvae.

Brook and brown trout, and certain panfish tolerated TFM as well as the rainbow trout. Brook trout were not harmed by exposure to 13.0 ppm, the highest concentration tested. Significant mortalities did not occur among brown trout and rock bass until the concentration exceeded 9.0 ppm. Yellow perch were affected at concentrations above 7.0 ppm. Where survival of these several species is desired, maximum concentrations of the chemical in streams can be reduced to protect them without altering the effectiveness of the larvicide treatment.

Among the so-called rough fishes, significant mortalities of adult suckers first occurred at concentrations of 7.0 ppm. Immature suckers were slightly less tolerant of the chemical than were the adults. Bullheads died in significant numbers when the concentration exceeded 3.0 ppm. They appear to be as susceptible to TFM as do the lampreys.

Forage fishes, such as shiners, chubs, dace, and sculpins were generally unaffected except at the highest concentrations of TFM used. Logperch, however, were killed by concentrations as low as 5.0 ppm.

Crayfish and caddisfly larvae were not affected by any concentration of the chemical used. Turtles likewise were unaffected.



Chemical feeding device in operation at the Silver River. Stock jar being filled with formulated TFM. Smaller hose carries mixture of water and chemical to perforated discharge pipe on bed of stream.

Perforated pipe discharging mixture of formulated TFM and water into the Silver River. Pipe has been raised above water level only for demonstration purposes.

Determining concentration of TFM in a stream water sample by colorimetric analysis.

Observers checking mortalities of caged larval lampreys during treatment of Mosquito River.

EXPERIMENTAL STREAM TREATMENTS

The raceway tests demonstrated that TFM could be metered successfully into running water to effect a complete kill of larval lampreys without damage to most other aquatic animals. Three tributaries of Lake Superior, infested with sea lamprey larvae, were selected for experimental applications of TFM to test the laboratory findings. These watersheds varied greatly in physical characteristics, ease of access, and length of stream requiring treatment. They were chosen for these reasons and because they offered unique possibilities for well-controlled experimentation. The three streams were: Mosquito River, Alger County, Michigan; Silver River, Baraga County, Michigan; and Pancake River watershed, District of Algoma, Ontario. Each experimental treatment is discussed separately in subsequent sections.

Foremost among the requirements for the successful application of TFM in streams are: (1) the precise determination of the minimum lethal dosage for larval lampreys and the maximum allowable dosage for a selected fish species in a particular water; (2) an accurate, controllable device for the metering of small amounts of a liquid formulation into the stream; and, (3) a precise method of analysing the treated water mass for TFM so that control of the concentration may be achieved.

Since the amount of TFM and the time required to treat a given stream cannot yet be determined from chemical analyses of the water, each application is based on pre-treatment bioassays conducted with water from the stream. All applications of TFM were immediately preceded by one or more such bioassays performed under conditions that were anticipated would exist in the stream at the time of treatment. Bioassay methods were essentially those described earlier in this report. Larval lampreys and rainbow trout were utilized as test animals. Only 4 replications were run at each concentration to restrict to a reasonable quantity the amount of test water needed at the laboratory. These bioassays were adequate for the accurate determinations of minimum lethal and maximum allowable dosages. Subsequent to the experiments reported here, a mobile laboratory has been constructed for pre-treatment bioassays. Placed at the site of each application, this facility greatly simplifies the performance of these necessary tests.

The efficient application of TFM requires a highly accurate and controllable pumping system that can be transported easily to remote locations. Two types of fluid-proportioning pumps have been used with varying degrees of success. In general, these pumps are arranged to feed a concentrated stock solution of TFM into a pipe containing a stream of water drawn from the river by a centrifugal pump. The initial dilution of TFM in this circulating system results in a more efficient dilution of the chemical in the river than does the direct introduction of undiluted formulation. The introduction of the diluted TFM into the river through a perforated pipe under considerable pressure aids in mixing the chemical with the water. Experiences with these fluid-proportioning systems are described in the reports of each stream treatment.

The pre-treatment bioassays show the concentration of TFM required to treat effectively a given stream. Stream flow is then determined at the point of introduction of the chemical and at the stream mouth to give some measure of the dilution of the toxicant which will occur over this reach of the watershed. From these data, the rate at which TFM must be fed into the stream is calculated, as follows:

$$F' = \frac{C \times F}{0.03713 \times C'},$$

where F' = rate of feed in U.S. gallons per hour
F = volume of flow of the stream in cfs at the point of introduction of the chemical
C' = concentration of stock solution in grams per liter
C = concentration of TFM in ppm desired in the stream at point of introduction

Because of inacuracies inherent in both the measurement of volume of flow and in the feed-rate adjustment of the pump, the initial concentration of the toxicant in the water is only an approximation of that desired. Furthermore, any change in the volume during treatment will alter the concentration of TFM. It is frequently necessary not only to adjust the initial feed rate but also to make subsequent changes to compensate for variations in stream flow. Obviously, a precise means of determining the concentration of TFM at any point in the stream is required. Accurate measurement of the amount of TFM was made by a method of colorimetric analysis based on the natural yellow color of the nitrophenols. Simply stated, the procedure involves the comparison of samples of treated stream water with standard solutions of TFM in a Klett-Summerson photoelectric colorimeter. This technique is rapid and accurate under field conditions; it has been described by Smith, Applegate, and Johnson (1960).

TREATMENT OF THE MOSQUITO RIVER

The Mosquito River in Alger County, Michigan, was treated on May 14, 1958, with the formulation of TFM known as Lamprecid 2770. The larvicide introduced into the river at a natural falls about 1¾ miles above the mouth. Sea lamprey larvae were found only below this barrier. Just prior to the treatment, the river had a discharge at the mouth of 39.8 cfs.

Pre-treatment studies of the stream included: a determination of the distribution of larval lampreys with an estimate of their numbers, and the determination of the kinds and relative abundance of fishes, and other vertebrate and invertebrate aquatic organisms; a check of rate of water movement and other hydraulic features of the stream, including the increase of flow through the reach to be treated; determination of chemical and other physical properties of the creek water at various locations in the watershed; the recording of water-temperature fluctuations for a 7-day period prior to the experiment; and, bioassay tests at the Hammond Bay Laboratory with water and larvae from the stream for the purpose of determining the minimum lethal and maximum allowable concentrations of the chemical (Table 7).

Prior to the treatment, larval lampreys were placed in 40 cages which were distributed in the river among 3 stations. These cages contained a total of 1,000 larvae. The condition of these larvae and the numbers dead at hourly intervals during the treatment were recorded.

A quantitative estimate of the effect of the treatment upon resident sea lamprey larvae was sought by intensive sampling of 4 marked areas of larval habitat. Two of these areas were fished with an electrical shocker and larvae removed before treatment; the remaining 2 areas were examined by the same method after treatmnt.

Lamprecid 2770 was applied to the river for 9 hours. A proportioning device called a Proportioneers Triplex Chem-O-Feeder was used. This feeder, which was equipped with Lucite heads and fittings, polyethylene tubing and neoprene diaphragm, check valves, and washers, was manifolded into the discharge side of a circulating pump. The circulating pump picked up untreated water from the stream and returned it (approximately 11 gpm) plus the chemical through a perforated pipe laid on the stream bottom. Pressure in the delivery pipe was maintained at approximately 20 psi to insure good mixing at the point of introduction.

It was intended to produce a concentration of 6 ppm of Lamprecid 2770 in the river. A mistake in the adjustment of the length of piston stroke at the beginning of the test resulted in a near doubling of the feed rate. This mistake was detected by analyses of treated water samples and was corrected in less than ½ hour. During the remainder of the test considerable difficulty was experienced in maintaining a consistent feed rate. Examination of the "feeder heads" after the trial indicated considerable crystallization and fragmentation of the lucite material. Fragments of lucite had almost completely clogged

TABLE 7.—Some physical and chemical properties of the waters of the streams treated experimentally with TFM and the biological activity of the larvicide in these waters as determined from pre-treatment bioassays.

[Tests conducted for a 24-hour period at water temperatures as indicated below.]

Source of test water	Test temperature (F.°)	Minimum lethal dose of TFM[1] (ppm)	Maximum allowable dose of TFM[2] (ppm)	Properties of test water				
				Conductivity (mMhos/18° C.)	CO_2 (ppm)	phth alk. (ppm)	M. O. alk. (ppm)	pH
Mosquito River, Alger County, Michigan	55	2.0	9.0	161.3	<1.0	0.0	163.3	8.0
Silver River, Baraga County, Michigan	55	1.0	4.5	60.3	<1.0	0.0	34.0	7.3
Pancake River, District of Algoma, Ontario	60	1.0	4.0	48.3	3.7	0.0	29.0	6.9
Gimlet Creek,[3] District of Algoma, Ontario	60	1.0	3.0	35.9	1.6	0.0	25.0	7.1

[1] Minimum dose required to kill 100 percent of the larval lampreys.

[2] Dose required to kill 25 ± percent of the rainbow trout.

[3] Tributary to the Pancake River.

the discharge check valves of all 3 heads. Other pump-component materials (Polyethylene and Neoprene) were not affected adversely.

Analyses of the treated stream water indicated that the larvicide was applied initially at a concentration of about 12 parts per million for a period not exceeding 30 minutes. Thereafter, the average concentration was in the order of 5.5 parts per million. The total amount of the formulation used was 45½ gallons. The total weight of the formulation applied was 385 pounds; the weight of active ingredient contained in this amount of formulation was approximately 163 pounds.

All larval lampreys confined to cages were dead after 7¾ hours of exposure to the chemical. Nearly complete kills of these control specimens were observed in a much shorter period; 91 percent were dead in 3½ hours, 97 percent in 4½ hours, and 99 percent had died within 5½ hours.

Dead and dying larvae were seen in the treated area of the stream after about 2 hours of exposure to the larvicide. Post-treatment examination of the marked sample areas revealed no live larvae. In addition to the latter areas, the larval habitat in some 1,400 linear feet of stream was examined intensively with electric shockers. This distance represented more than 15 percent of the entire area of stream treated and included 4,569 square feet of larval habitat. Within this area no sea lamprey larvae and only 4 live American brook lampreys (*Lampetra lamottei*) *were found.*

Only 7 species of fishes were found in the Mosquito River (Table 8). Brook trout and resident rainbow trout were common and a sub-

TABLE 8.—Common and scientific names of lampreys and fishes found in the Mosquito River, Alger County, Michigan.

Common name	Scientific name
American brook lamprey	*Lampetra lamottei*
Blacknose dace	*Rhynichthys atratulus*
Brook stickleback	*Eucalia inconstans*
Brook trout	*Salvelinus fontinalis*
Central mudminnow	*Umbra limi*
Mottled sculpin	*Cottus bairdi*
Rainbow trout	*Salmo gairdneri*
Sea lamprey	*Petromyzon marinus*
Spottail shiner	*Notropis hudsonius*

stantial number of lake-run rainbow trout were present, or migrating into the stream, during the time of the test. Other resident fishes consisted of shiners, dace, mudminnows, sculpins, and sticklebacks. Dragonflies, mayflies, caddisflies, stoneflies, dipterans, and aquatic earthworms were also present.

During the trial and in post-treatment examinations of the stream only one fish was found which could conceivably have been harmed by the larvicide. This fish was a large, lake-run rainbow trout which bore 2 fresh lamprey scars and was spent. Other lake-run rainbow trout which had been building nests and spawning prior to the application remained more or less quietly on or near their redds while the chemical was in the river. Authentic records were obtained of the capture of 4 lake-run fish on lures during the treatment. No effect of the larvicide upon the aquatic invertebrates was observed.

TREATMENT OF THE SILVER RIVER

The Silver River, Baraga County, Michigan, was treated with Lamprecid 2770 on June 11, 1958. The larvicide was introduced into the river just above a natural falls some 4½ miles upstream from the mouth. Spawning-run sea lampreys reportedly cannot pass over these falls and larval sea lampreys were found only below this barrier. Just prior to the treatment, the river had a discharge at the mouth of 80.0 cfs.

Pre-treatment examination of the stream was similar to that of the Mosquito River. The relative numbers and distribution of larval lampreys were determined, as were the kinds and relative abundance of fishes and of other vertebrates and invertebrates. Water movement and flow patterns were checked with fluorescein dye. Volume of flow was determined and water analyses were made at various points in the area to be treated. Water temperatures were recorded for 2 weeks prior to the test. At the laboratory, bioassay tests were conducted in water and with larvae from the river (Table 7).

Prior to the treatment, a total of 1,205 larval lampreys were placed in the river in 50 cages distributed among 5 stations. The condition of these larvae and the numbers dead were recorded at hourly intervals during the treatment.

The effect of the application upon resident sea lamprey larvae was evaluated by intensive pre- and post-treatment sampling of over 100,000 square feet of larval habitat. Approximately one-half of this area was examined with electric shockers before treatment and all larvae captured were removed from the stream; the remaining area was examined by the same method after treatment.

Lamprecid 2770 was applied to the river for 13½ hours with a Proportioneers Model 1106D direct-displacement, dual-piston chemical feeder. Both discharges of this pump were manifolded into the discharge side of a circulating pump. The latter picked up untreated water above the point of introduction and delivered this water plus the chemical into the stream through a perforated pipe laid across the stream bed. Pressure in the delivery pipe was maintained at 20 psi.

Application of the larvicide started at a feed rate intended to produce a concentration of 3.0 ppm of the active ingredient in the stream immediately below the point of introduction. Analyses of treated stream water indicated a concentration of 2.8 ppm in this locale. This deficiency was so small that it did not warrant adjustment of the feeder. The initial rate was therefore maintained without interruption throughout the entire period of application. A total of 128 gallons of formulation was used. The total weight of the formulation applied was 1,280 pounds; the weight of active ingredient contained in this amount of formulation was 583.5 pounds.

All larval lampreys confined to cages were dead after 8½ hours of exposure to the chemical. Nearly complete kills of these control specimens were observed in a much shorter period; 85.3 percent were dead in 4 hours, 97.7 percent in 5 hours, and 98.6 percent had died within 6 hours.

Some dead and dying larvae were seen in the treated areas of the stream after about 1½ hours of exposure to the larvicide. Subsequently, many thousands were seen dead in the river.

Estuarine conditions in this river had not been encountered before. A long, sluggish estuary is present that merges gradually into the narrow head of a finger-like bay. During the spring and summer seiches, which occur at less than hourly intervals, alter the water level of bay and estuary to a considerable degree. It was considered possible that the cyclic, tidal-like in-flows of water would dilute the treated discharge from the river to a concentration below the lethal level. This possibility was important since the estuarine waters were inhabited by a great number of larvae; they were also known to be present in the shallower waters at the head of the bay.

Analyses of water samples from the estuary and bay indicated that concentrations of the larvicide were initially erratic in this area. Subsequently, a uniform concentration of 2.2 ppm became established in the entire zone and to a point approximately ½ mile out in the bay. This condition persisted for many hours. Inspections on foot and by boat revealed many dead larvae lying on the bed of the bay out to the limit of visibility (depths of about 6 feet).

The post-treatment examinations with electrical shockers covered approximately 50,000 square feet of larval habitat in the river proper and in the estuary. In the latter area the examination extended to depths of 4 feet but also included other parts of the channel that were periodically above water level after the seiches ebbed. Only 1 live larval lamprey was found. This individual was situated within the entrance of a small tributary of the river proper.

The Silver River is known to contain 25 species of fishes, in addition to 4 species of lampreys (Table 9). At the time of treatment, brook trout and rainbow trout (both resident and migrant) were present. White suckers and bullheads were migrating into the stream. The most abundant forage species (resident and migrant), were spottail shiners, blacknose dace, longnose dace, logperch, Johnny darters, and sculpins.

Among all fishes present, only the logperch was affected in any significant degree by the larvicide. Occasional individuals of most species present succumbed to the toxin. Post-treatment examination of the stream indicated that even the logperch, seemingly most susceptible to the chemical, was still present in substantial numbers. Other species seemed to be as abundant as they were prior to the application.

No significant effect of the chemical was observed upon the aquatic invertebrates in the stream except for one species of mayfly, which appeared to be stimulated to a premature "hatching."

TREATMENT OF THE PANCAKE RIVER AND ITS TRIBUTARY, GIMLET CREEK

The Pancake River and Gimlet Creek were treated concurrently on August 26 and 27, 1958, with Lamprecid 2770. The larvicide was introduced into the Pancake River about 12 miles above its mouth. The river has 3 natural falls, only one of which was considered an effective barrier to spawning-run sea lampreys, between the point of introduction of the larvicide and the stream mouth. TFM was introduced into Gimlet Creek about 3 miles above its confluence with the Pancake River just above a series of 6 beaver dams. Immediately prior to the treatments, the total discharge of the Pancake River was 37.0 cfs and that of Gimlet Creek was 5.7 cfs. Pre-treatment examinations of the streams included all of the procedures outlined for the previous stream trials of TFM (Table 7).

Before the experiment was started, 1,200 larval lampreys were placed in the two rivers in 50 cages; 30 cages were divided among 3 stations in the Pancake River and 20 among 4 stations in Gimlet Creek. The condition of the larvae and the numbers dead were recorded at hourly intervals during the treatment.

The application of Lamprecid 2770 was begun in Gimlet Creek on August 26 and in the Pancake River on August 27, about 36 hours later. This interval was established, on the basis of the timing of downstream movements of dye, so that the two treated water masses would reach the confluence of the streams simultaneously. The feeders at

TABLE 9.—Common and scientific names of lampreys and fishes found in the Silver River, Baraga County, Michigan.

Common name	Scientific name
American brook lamprey	*Lampetra lamottei*
American smelt	*Osmerus mordax*
Blacknose dace	*Rhynichthys atratulus*
Brook Stickleback	*Eucalia inconstans*
Brook trout	*Salvelinus fontinalis*
Brown bullhead	*Ictalurus nebulosus*
Burbot	*Lota lota*
Common shiner	*Notropis cornutus*
Creek chub	*Semotilus atromaculatus*
Golden shiner	*Notemigonus crysoleucas*
Hornyhead chub	*Hybopsis biguttata*
Johnny darter	*Etheostoma nigrum*
Logperch	*Percina caprodes*
Longnose dace	*Rhinichthys cataractae*
Longnose sucker	*Catostomus catostomus*
Mottled sculpin	*Cottus bairdi*
Northern brook lamprey	*Ichthyomyzon fossor*
Northern pike	*Esox lucius*
Rainbow trout	*Salmo gairdneri*
Redhorse sucker	*Moxostoma* sp.
Rock bass	*Ambloplites rupestris*
Sea lamprey	*Petromyzon marinus*
Silver lamprey	*Ichthyomyzon unicuspis*
Smallmouth bass	*Micropterus dolomieui*
Spottail shiner	*Notropis hudsonius*
Trout-perch	*Percopis omiscomaycus*
Walleye	*Stizostedion v. vitreum*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

both points of introduction were the direct-displacement, dual-piston. type previously tested at the Silver River. Application techniques with this equipment were identical to those of the earlier test.

The introductions of larvicide, both in Gimlet Creek and in Pancake River, were begun at rates intended to produce concentrations of 3.0 ppm of the active ingredient in the streams immediately below the points of application. Analysis of the treated water in Gimlet Creek showed an initial concentration of 4.8 ppm; the feed rate was reduced to give a concentration of 2.5 to 3.3 ppm for the duration of the treatment. A total of 6 gallons of formulation, containing 28 pounds of active ingredient, was applied over a period of 12 hours in Gimlet Creek. Analysis of the treated water in the Pancake River showed an initial concentration of 3.7 ppm at the point of introduction; the feed rate was reduced to give a concentration of 2.4 to 2.6 ppm for the duration of the treatment. A total of 33 gallons of formulation, containing 155 pounds of the active ingredient, was applied in Pancake River over a period of 12 hours.

The captive larval lampreys nearest the feeder site in Gimlet Creek were dead by the end of 5 hours of exposure to the toxicant; those located nearest the mouth were dead after 8½ hours. The caged larvae nearest the feeder site in the Pancake River were dead after 5 hours of exposure to the chemical and those near the mouth were dead after about 7 hours, with the exception of larvae in two cages located in a semi-isolated part of the estuary. The incomplete effectiveness of the treatment in the latter area (approximately 1,000 square yards) is attributed to the restricted exchange of water between it and the estuary proper. There was a complete kill among caged larval lampreys at all other stations.

Dead and dying lamprey larvae were observed in Gimlet Creek and Pancake River within 2 to 3 hours of the beginning of the respective treatments. Estimates of the total number of dead lamprey larvae ranged between ½ and ¾ million. Immediately after the treatments, several thousand dead larval lampreys were collected, and identified. Roughly one-third were sea lampreys. In the Pancake River, this species occurred only below the lowermost falls (about 3 miles from the mouth), but in Gimlet Creek dead sea lamprey larvae were found between the uppermost beaver dam and the feeder site.

Post-treatment examinations of at least 50 percent of the larval habitat of both the Pancake River and Gimlet Creek were made with electric shockers. The survey of the Pancake River was confined to the area in which dead sea lamprey larvae had been found. In Gimlet Creek, 38 live larval lampreys were taken during the post-treatment shocker survey—all of them were American brook lamprey and all were found in isolated oxbows, or in the mouth of one small tributary. In the Pancake River, 3 live American brook lampreys were recovered near the mouth of Gimlet Creek. The semi-isolated bay in the estuary of the Pancake River yielded 10 live larvae of *Ichthyomyzon* sp. and 7 of the American brook lamprey. No live sea lamprey larvae were recovered after the treatments of Gimlet Creek and Pancake River.

At least 18 species of bony fishes were known to occur within the Pancake River system (Table 10). At the time of treatment, rainbow trout, brook trout, white suckers, sculpins, burbot, and several species of minnows and of darters were present. The sculpins appeared to suffer fairly heavy mortalities from the toxicant. A few longnose dace and burbot were killed as were a very small number of rainbow trout.

TABLE 10.—Common and scientific names of lampreys and fishes found in the Pancake River watershed, District of Algoma, Ontario.

Common name	Scientific name
American brook lamprey	*Lampetra lamottei*
American smelt	*Osmerus mordax*
Brook stickleback	*Eucalia inconstans*
Brook trout	*Salvelinus fontinalis*
Burbot	*Lota lota*
Common shiner	*Notropis cornutus*
Johnny darter	*Etheostoma nigrum*
Lake chub	*Hybopsis plumbea*
Logperch	*Percina caprodes*
Longnose dace	*Rhynichthys cataractae*
Mottled sculpin	*Cottus bairdi*
Ninespine stickleback	*Pungitius pungitius*
Northern pike	*Esox lucius*
Rainbow trout	*Salmo gairdneri*
Rock bass	*Ambloplites rupestris*
Sea lamprey	*Petromyzon marinus*
Silver lamprey	*Ichthyomyzon unicuspis*
Spottail shiner	*Notropis hudsonius*
Trout-perch	*Percopsis omiscomaycus*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

The applications of larvicide caused a premature emergence of mayfly nymphs, but did not appear to affect other groups of invertebrates seriously. For no species, other than the lampreys, did the mortality appear to be so severe that the animal could not restore its numbers rapidly by natural means.

ACKNOWLEDGMENTS

The authors wish to extend their thanks to the many staff members of the U. S. Bureau of Commercial Fisheries and the Fisheries Research Board of Canada who assisted us in collecting data during our experimental stream treatments. We particularly wish to thank Dr. E. E. Dunn of the Dow Chemical Company for his assistance in arranging for analysis of milk samples during our mammalin toxicity tests. Mr. Henry Armbrust of Proportioneers, Inc. assisted us in the design of our chemical feeding equipment. Mr. H. E. Maurer of the Hostachem Corporation was instrumental in expediting the development of the commercial formulation of TFM used in much of our work. Test fishes utilized in our bioassays were supplied by the Michigan Conservation Department.

These studies and experiments were supported by the Great Lakes Fishery Commission.

LITERATURE CITED

Applegate, Vernon C.

1950. Natural history of the sea lamprey (*Petromyzon marinus*) in Michigan. U. S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 55, 237 pp.

Applegate, Vernon C., Bernard R. Smith, and Willis L. Nielsen

1952. Use of electricity in the control of sea lampreys: Electro-mechanical weirs and traps and electrical barriers. U. S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 92, 52 pp.

Applegate, Vernon C. and James W. Moffett

1955. The sea lamprey. Scientific American, Vol. 192, No. 4, pp. 36–41.

Applegate, Vernon C., John H. Howell, A. E. Hall, and Manning A. Smith

1957. Toxicity of 4,346 chemicals to larval lampreys and fishes. U. S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 207, 157 pp.

1958. Use of mononitrophenols containing halogens as selective sea lamprey larvicides. Science, Vol. 127, No. 3294, pp. 336–338.

Erkkila, Leo F., Bernard R. Smith, and Alberton L. McLain

1956. Sea lamprey control on the Great Lakes—1953 and 1954. U. S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 175, 27 pp.

Smith, Manning A., Vernon C. Applegate, and B. G. H. Johnson

1960. Colorimetric determination of halogenated nitrophenols added to streams as sea lamprey larvicides.
Analytical Chemistry, Vol. 32, No. 12, pp. 1,670–1,675.

APPENDIX I

TOXICITY OF TFM TO MAMMALS

The effect of TFM on mammals had to be learned before large quantities of concentrated formulations could be handled or dilutions of the chemical introduced safely into public waters. TFM was found to be highly toxic, both internally and externally, to mammals in its crystalline form and as a concentrated stock solution. Tests performed by the Wisconsin Alumni Research Foundation with a 20-percent (by weight) formulation of TFM showed an acute oral LD 50 for the rabbit of approximately 0.16 g./kg. The acute dermal LD 50 was approximately 1.6 g./kg. The primary skin irritation index was approximately 2.6, *i.e.,* that of a moderate skin irritant. TFM is essentially innocuous as an eye irritant at least at stream concentrations. Extreme care must be exercised in handling concentrated forms of TFM. Protective clothing, rubber gloves, and face masks or goggles are necessary for the minimum protection of handlers.

The very low concentrations of TFM required to kill larval lampreys in streams are harmless to wildlife and livestock. Game biologists of the Michigan Department of Conservation tested the effects of a 13 ppm solution of the sodium salt of TFM on deer. Penned animals exposed to treated drinking water for 3 days showed no ill effects, either short- or long-term. Other test deer, exposed to a choice of both treated and untreated drinking water, actually showed a preference for water containing the chemical.

The effects of the consumption of TFM-treated drinking water upon the milk, milk products, and general health of dairy cows were determined by a veterinary, Dr. Albert Dobias, of Cheboygan, Michigan, who conducted experiments with 6 1,000-lb. cows (5 Holstein and 1 Durham) and 4 Holstein calves approximately 10 months old. Two Holsteins and the Durham cow were used as test animals and 3 Holsteins served as controls. In addition, 2 Holstein calves were used as test animals and 2 as controls. Test cows and calves were exposed for 24 hours to water containing 13 ppm of the sodium salt of TFM. It was prepared from the commercial formulation known as Lamprecid 2770 and represented the maximum concentration of TFM likely to be used in streams.

Urine samples were taken from all animals and milk samples from the cows prior to exposure of some to the TFM-treated water and at intervals of 12, 24, 48, 120, and 240 hours during and after exposure; these samples were refrigerated and subsequently analyzed for TFM. Urinalysis for sugar, albumen, acetone, and blood was conducted by use of an Ames diagnostic kit for both test and control cows.

Other data recorded were: milk production, temperature, pulse, and respiration. The water consumption by both test and control animals was measured during the 24-hour exposure.

No harmful effects upon the animals were observed. The test animals drank less of the chemically treated water than the control animals did of the untreated water. This difference may have been due to the objectionable taste or smell of the chemical. Milk production did not drop nor did the milk have any detectable off-odor. All animals appeared to be normal during and after the study. Analyses of the milk and urine samples, conducted by the Dow Chemical Company, revealed that small quantities of TFM were excreted in the urine. The phenol could not be detected in the milk even with ultrasensitive analytical procedures.

SYMPOSIUM ON EQUATORIAL CIRCULATION IN THE PACIFIC

Distribution of Properties about the Equatorial Undercurrent

RICHARD A. BARKLEY and THOMAS S. AUSTIN, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, U.S.A.

The DOLPHIN expedition, carried out in connection with the IGY in 1958, was a joint undertaking of the Scripps Institution of Oceanography and the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, to study the Equatorial Undercurrent (Cromwell Current) by means of standard oceanographic techniques and direct current measurements.

Sections are given showing the distribution of salinity, temperature, and dissolved oxygen along 140°W. between 4°N. and 4°S. and along the Equator from 140°W. to the Galapagos Islands. The significant features of these sections are related to the currents and water-mass properties. North-south asymmetry in the distribution of both salinity and oxygen are attributed to the sources of water entering the Undercurrent. An analysis of the internal pressure distribution (relative to that at 1,000 m.) shows that a zonal pressure gradient exists above 600 m. along the Equator which tends to accelerate the eastward flow between 140°W. and about 114°W.; from 114°W. to about 97°W. there is little evidence of any zonal pressure gradient, while to the east of 97°W. the gradient is reversed and would tend to decelerate an eastward-moving current. The effects of these gradients on the Equatorial Undercurrent, and the resulting distribution of properties, are discussed.

4

INTER - AMERICAN TROPICAL TUNA COMMISSION
COMISION INTERAMERICANA DEL ATUN TROPICAL

Bulletin – Boletín
Vol. V, No. 2

STUDIES OF THE AGE, GROWTH, SEXUAL MATURITY AND SPAWNING OF POPULATIONS OF ANCHOVETA (*CETENGRAULIS MYSTICETUS*) OF THE COAST OF THE EASTERN TROPICAL PACIFIC OCEAN

ESTUDIOS DE LA EDAD, CRECIMIENTO, MADUREZ SEXUAL Y DESOVE DE LAS POBLACIONES DE ANCHOVETA (*CETENGRAULIS MYSTICETUS*) DE LA COSTA DEL OCEANO PACIFICO ORIENTAL TROPICAL

by — por

IZADORE BARRETT and - y GERALD V. HOWARD

La Jolla, California
1961

INTER - AMERICAN TROPICAL TUNA COMMISSION
COMISION INTERAMERICANA DEL ATUN TROPICAL

Bulletin – Boletín
Vol. V, No. 2

STUDIES OF THE AGE, GROWTH, SEXUAL MATURITY AND SPAWNING OF POPULATIONS OF ANCHOVETA (*CETENGRAULIS MYSTICETUS*) OF THE COAST OF THE EASTERN TROPICAL PACIFIC OCEAN

ESTUDIOS DE LA EDAD, CRECIMIENTO, MADUREZ SEXUAL Y DESOVE DE LAS POBLACIONES DE ANCHOVETA (*CETENGRAULIS MYSTICETUS*) DE LA COSTA DEL OCEANO PACIFICO ORIENTAL TROPICAL

by — por

IZADORE BARRETT and - y **GERALD V. HOWARD**

La Jolla, California
1961

CONTENTS — INDICE

ENGLISH VERSION — VERSION EN INGLES

Page
SUMMARY 115
INTRODUCTION 116
METHODS 117
  Age and growth 117
  Sexual maturity and spawning 120
RESULTS 121
  Almejas Bay 121
    Age and growth 121
    Sexual maturity and spawning 123
  Guaymas 124
    Age and growth 124
    Sexual maturity and spawning 127
  Ahome Point 128
    Age and growth 128
    Sexual maturity and spawning 130
  Banderas Bay 130
    Age and growth 130
    Sexual maturity and spawning 131
  Gulf of Fonseca 132
    Age and growth 132
    Sexual maturity and spawning 134
    Time of spawning 134
    Frequency of spawning in a season 135
    Relation of gonad index to sexual maturity 135
  Colombia 135
    Age and growth 135
    Sexual maturity and spawning 137
  Ecuador-Peru 137
    Age and growth 137
    Sexual maturity and spawning 139

FIGURES — FIGURAS 140

TABLES — TABLAS 165

SPANISH VERSION — VERSION EN ESPAÑOL

Página
RESUMEN 188
INTRODUCCION 189
METODOS 190
  Edad y crecimiento 190
  Madurez sexual y desove 193
RESULTADOS 195
  Bahía de Almejas 195
    Edad y crecimiento 195
    Madurez sexual y desove 197
  Guaymas 199
    Edad y crecimiento 199
    Madurez sexual y desove 201
  Punta Ahome 203
    Edad y crecimiento 203
    Madurez sexual y desove 204
  Bahía Banderas 205
    Edad y crecimiento 205
    Madurez sexual y desove 206
  Golfo de Fonseca 207
    Edad y crecimiento 207
    Madurez sexual y desove 209
    Epoca del desove 209
    Frecuencia del desove en una estación 210
    Relación entre el índice de gónadas y la madurez sexual 210
  Colombia 211
    Edad y crecimiento 211
    Madurez sexual y desove 212
  Ecuador-Perú 213
    Edad y crecimiento 213
    Madurez sexual y desove 214

LITERATURE CITED — BIBLIOGRAFIA CITADA 216

STUDIES OF THE AGE, GROWTH, SEXUAL MATURITY AND SPAWNING OF POPULATIONS OF ANCHOVETA *(CETENGRAULIS MYSTICETUS)* OF THE COAST OF THE EASTERN TROPICAL PACIFIC OCEAN

by

Izadore Barrett and Gerald V. Howard[1]

SUMMARY

Three hundred and twenty-six collections of anchoveta *(Cetengraulis mysticetus)*, an important tuna bait species, taken between April 1951 and April 1960 from seven major baiting areas in the Eastern Tropical Pacific Ocean—Almejas Bay, Guaymas, Ahome Point, Banderas Bay, Gulf of Fonseca, coast of Colombia and Ecuador-Peru—are the basis of this study of age, growth, sexual maturity and spawning. The study of the temporal progression of modal size groups from plots of monthly length-frequency distributions provided estimates of age and rate of growth. The study of sexual maturity and time of spawning was based on gross examination of ovaries, and application of the gonad index.

The tabulation below indicates the approximate mean lengths at ages I, II and III, and the probable periods of spawning at each area.

	I	II	III	
Almejas Bay	127	146	—	August to February
Guaymas Bay	128	141	—	July to December
Ahome Point	132	144	—	June to September
Banderas Bay	115	—	—	Some time from June to December
Gulf of Fonseca	128	143	160	September to December
Gulf of Panama[1]	126	148	—	October to December
Colombia	126	142	—	October to February
Ecuador-Peru	118	141	—	December to February

[1] From Howard and Landa, 1958

Anchoveta, over their geographic range, have an average length of from 115 to 132 mm. at the end of their first year and from 141 to 148 mm. at the end of their second year. Fish of average size longer than this are in their third or older year. Anchoveta in their first year comprised more than 78 per cent of the populations in all areas except the Gulf of Fonseca and along the coast of Colombia. In these latter areas, the largest proportion of fish were in their second year (54 and 59 per cent, respectively). Only at the Gulf of Fonseca were anchoveta in their third year present in substantial proportion (12 per cent).

---

[1] Present address: U.S. Bureau of Commercial Fisheries, Biological Laboratory, San Diego, California

Spawning in all areas is usually in the latter months of the year, and may extend into the first months of the year. The spawning period may last from three to seven months, in the different areas. The anchoveta spawns for the first time at the end of its first year, and again at the end of its second and, possibly, third years.

INTRODUCTION

The anchoveta *(Cetengraulis mysticetus),* the most important bait fish used to catch tunas in the Eastern Tropical Pacific Ocean, is taken by fishermen in widely separated bays and estuaries from Baja California, Mexico to Peru. The Commission obtains detailed records of the amounts caught in each baiting area and the amount of effort employed to catch these quantities (Alverson and Shimada, 1957). Such fishing records assist in measuring, and eventually predicting changes in abundance and yield of these populations but their proper interpretation requires a knowledge of the life history and ecology of the species. Through the generous cooperation of the tuna fleet, the Commission has obtained, since 1951, collections of anchovetas from the major baiting areas for studies of the biology and life history. These samples have been supplemented, whenever possible, by collections made by the staff, and by local fishermen in some of the more remote areas.

Meristic and morphometric studies of representative collections by Howard (1954) and Berdegué A. (1958) have shown that there is no free inter-change of anchovetas between the major baiting areas and that the populations are probably discrete units. The several populations of anchovetas are, therefore, being treated separately for studies of their biology.

Besides the racial investigations mentioned, the principal purpose for which the tuna boat collections have been used is for studies of age, growth, sexual maturity and spawning. For the latter it is necessary to have collections from each area throughout the year. Since the baiting areas are frequented by the tuna fleet only when tuna fishing is productive in adjacent areas, it takes several years to obtain the required series of collections for each region. In fact, collections for all months of the year are not yet available for most localities.

The Commission has maintained a laboratory in Panama for the study of the biology and ecology of the anchoveta population of the Gulf of Panama since late in 1954. Personnel there have collected samples of anchovetas for age, growth and spawning studies. These collections, together with those made by the tuna boats, provided a complete annual series of data from this region well before adequate material was available elsewhere.

The results of the investigations of the age, growth, sexual maturity and spawning of the anchoveta in the Gulf of Panama were published by Howard and Landa (1958). The present study reports on the current knowledge of these aspects of the life history of the anchoveta in other baiting areas. These regions include Almejas Bay, Guaymas, Ahome Point, Banderas Bay, Gulf of Fonseca, coast of Colombia and Ecuador-Peru. Their geographic location is shown in Figure 1.

Collections of anchoveta for this study were taken between April 1951 and April 1960 and are from seven major baiting areas in the Eastern Tropical Pacific. There were 326 in number consisting of 38,726 fish. A detailed summary of the number of collections and the number of specimens taken in each area is provided in Table 1.

METHODS

The techniques that were used in this study of the age, growth, sexual maturity and spawning are essentially the same as those described by Howard and Landa (1958) in their study of the anchoveta population in the Gulf of Panama. An analysis of length-frequencies was used to determine age and rate of growth. The study of sexual maturity and time of spawning was based on gross examination of ovaries and application of the gonad index which these authors devised. Ova were measured from one region—the Gulf of Fonseca.

Age and growth

The reading of scales or interpretation of marks or bands of differentiated areas of other hard parts was not considered for the age and growth analysis. Howard and Landa pointed out that an examination of the scales of the anchoveta would be difficult and time consuming. A subsequent examination of the scales from Panama by Clifford L. Peterson (unpublished data) indicates that they are of no value for determining age, in this area at least. It was thought that a study of other hard parts, such as otoliths, would not be any more fruitful. Application of the length-frequency method for determining age and growth involved a study of the temporal progression of modal size groups from plots of monthly length-frequency distributions.

The standard length of each fish was measured to the nearest millimeter from the tip of the snout to the end of the silvery area on the caudal peduncle. The frequencies for each length in any one month were combined and converted to percentages of the total for the month to permit comparison with collections from other months and other areas. The values were plotted as monthly percentage length-frequency distributions. The latter are shown in accompanying figures. Numbers on the right side of each panel indicate the numbers of collections and specimens measured.

Limitations to the use of the length-frequency method for obtaining estimates of the age and growth of anchoveta imposed by the effect of overlapping length distributions of older fish, and by the use of samples possibly not representative because of schooling and selective fishing were discussed in detail by Howard and Landa (1958). These limitations to the use of the length-frequency method are similarly applicable in this study. Its use was further limited by the occurrence in some areas of irregular or extending spawning, which often modified the peaks in the length-frequency distributions. Within these limitations, however, the technique gave a generally consistent estimate of the age and growth of anchoveta.

Size selection by the tuna fishermen and the off-shore habitat of juvenile anchoveta reduce the suitability of the anchoveta collections made by the tuna fishermen for estimating the age composition of the stocks. This was discussed in detail by Howard and Landa (1958). Nevertheless, even a rough estimate of the proportion which each age group contributes to the catch in the major baiting areas is useful.

The monthly length percentage-frequency distributions were inspected to ascertain the presence of modes and their significance. The distributions usually showed one or two modes that could be followed serially (with occasional breaks) through the year. For each area, the month having the modal group of fish of minimum size was noted. Since it was demonstrated for each of the areas (page 135) that the anchoveta spawns only once annually and since the smallest fish were present only shortly after spawning, these small fish had to represent the incoming age group ('age group' is used to denote fish of a particular age).

A second modal group containing larger fish was frequently found concurrent with the modal group containing the smaller fish. There was a steady progression to the right, in succeeding months, of the first mode (which contained fish in their first year) until this group itself formed the second modal group in the next year.

It was relatively simple to distinguish modal groups representing fish in their first year from those containing fish in their second year, during the first few months after recruitment, because of the comparatively large difference in the lengths of the fish in the two age groups. With time, the fish in their first year grew so rapidly that there was often no distinct gap between the modal groups. There was a tendency of the larger fish of the first year group to overlap the smaller of the second year group, making separation of the two difficult. Arbitrary criteria were established to separate what were obviously two age groups, as indicated by the size ranges.

In many months, there was a definite break between the two modal groups and separation was simple. Where no definite break occurred, the lowest frequency between the two peaks was considered to be the dividing point. In some months, there was a certain overlapping of distributions for one or two months, but a knowledge of the size ranges of the modal groups in the preceding and succeeding months suggested where the break in the age group might be made. In some months, only one modal group was present and these fish were considered to be in their first or second year on the basis of their size range. It should be noted that these artificial separations cut off the upper size limit of the younger fish and the lower size limit of the older fish. Howard and Landa (1958) showed that the criteria used here for the separation of the frequency groups were as reasonable as those involving the use of probability paper, and were as valid.

After the age groups were separated out, the mean length and the size range for each age group in each month were determined. These data, as well as the number of fish in each age group, were tabulated. Some inconsistencies in the orderly increase of the mean lengths from month to month were apparent, due to the deficiencies in the sampling technique (page 117), but there was a consistent temporal increase in mean lengths.

The lack of collections or the small number of specimens in a collection in some months made it difficult to get a consistent estimate of the growth rate of the anchoveta from each year's collections. The time of spawning and of the entry of the young into the population varies little in most areas from year to year. For these areas, the length percentage-frequencies for each month for all years of collection were combined and an average struck. These were plotted to show the over-all length percentage-frequency distributions for all the data combined for each calendar month over the entire period of the collections. Consolidation was made by combining the percentage-frequency distribution rather than the actual frequencies.

These length percentage-frequency distributions for all the years combined were analyzed by the same method as were those for individual months. The age groups were separated out, and the size ranges and the mean lengths were calculated. The consolidation of the data often indicated new points of separation between the age groups. The resultant monthly size ranges and mean lengths do not, therefore, necessarily correspond to those which would result by summing and averaging the monthly mean lengths for all years.

Growth of the anchoveta was shown by plotting the monthly mean lengths of the age group against time. The mean lengths by month for all the years combined and the mean lengths by month for each year have been plotted for each of the areas, where feasible. The vertical lines denote the range in length between the smallest and the largest anchoveta in each month for all the years' data combined.

For areas where the collections were meager (Colombia, Banderas Bay, and Ecuador-Peru), only the monthly length percentage-frequency distributions for all the years combined are presented. However, data for the individual months' collections are given in tabular form.

Sexual maturity and spawning

The study of the sexual maturity and spawning of the anchoveta was undertaken to determine the time and duration of spawning, and the periods of peak spawning, for each of the areas; the frequency of spawning within a season, for an area other than the Gulf of Panama which was examined by Howard and Landa (1958); and the ages at first and subsequent maturity. Analytical techniques similar to those of Howard and Landa were used.

Some 25 to 50 specimens from many of the collections were retained for maturity and spawning studies. The gonads of all the fish available for examination were inspected. The appearance of the gonads has been described in detail by Howard and Landa. The ovaries were measured at the point of maximum width with a pair of dividers. For the specimens from the Gulf of Fonseca, a piece of the ovary of each female was inspected for the presence of discernible eggs, larger than 0.20 mm. If present, 100 of these eggs were measured (Howard and Landa, 1958, p. 407). Measurements of the testes were not made, but the males were classified, when possible, as immature, mature or spent. The presence in the collections of fish too immature to sex or of spent fish was noted.

Howard and Landa (1958) developed the following gonad index to indicate sexual development of the female anchoveta in the Gulf of Panama:

$$\text{Gonad index} = \frac{\text{width of gonad (mm.)} \times 10^2}{\text{standard length of fish (mm.)}}$$

They showed that the gonad index value is directly related to ovarian development as measured by mean egg length and that spawning reaches a peak when the average gonad index for the population is at a maximum.

Validity of the use of this gonad index for anchoveta in other areas was tested and confirmed by using material collected from the Gulf of Fonesca (page 135). On this basis, the use of the gonad index to describe sexual maturity and spawning in all the baiting areas was accepted.

Three gonad index classes were established to describe the stages of sexual maturity. The classes were derived from the relationship between the spawning season and the value of the gonad index for anchoveta in the Gulf of Panama. Peak spawning occurs in the Gulf of Panama in November and December (Howard and Landa, 1958). Female anchoveta with gonad indices greater than class 6 were most prevalent in the population there at that time. These fish can be considered most advanced sexually; when they were found in the collections from the areas under study here, spawning was assumed to be in progress. The numbers of anchovetas with gonad indices in classes 3 to 6 decreased from a November peak, as the numbers of anchoveta in the greater-than-6 class increased, in the Gulf of Panama. These fish can be considered to be approaching the advanced sexual stage; their presence in the populations under study was taken to indicate immediately impending spawning. Anchoveta with gonad index values less than three were most abundant in October, before the peak of the spawning season in the Gulf of Panama. These fish can be considered to be maturing; their presence in the collections studied here was taken to indicate the earliest signs of sexual development. Anchovetas whose gonads were seen as thin filaments from which it was not possible to determine the sex by gross examination were considered immature.

The time of peak spawning was considered to be those months when the percentage of females in the population with gonad indices greater than 6 was at a maximum. The duration of the spawning season was judged to be from the first appearance in the population of anchoveta approaching advanced sexual maturity to the last appearance of anchoveta in the advanced sexual stage. These inferences were supported by the decrease in the number of immature anchoveta as the spawning season approached and the increase in the number of spent fish as it ended. The degree of maturity of the males, from cursory examination, supplied corroborative evidence. The time of appearance of the smallest fish in the population served as a further indication of the time of spawning.

The frequency of spawning in a season can be determined from the study of succeeding batches of maturing eggs in an ovary. When the composite length-frequency distribution of egg measurements from samples of maturing females are grouped according to the position of the last mode in the distribution, inspection shows the number of maturing batches of eggs (Clark, 1934). The procedure is explained also in Howard and Landa (1958) and is discussed in detail on page 135 for the Gulf of Fonseca.

The age of the anchoveta at first and subsequent maturities was determined by comparing the length-frequency distributions of sexually advanced females (gonad index 6 or greater) in a month when peak spawning occurred with the length-frequency distribution of all the anchoveta in that same month, for all the years combined. Inferences as to the lengths (and ages) of the spawning portion of the population in relation to the lengths (and ages) of the entire population were drawn from inspection of the distributions.

RESULTS

Almejas Bay

Age and growth

One hundred and nine collections containing 14,097 anchovetas were made at Almejas Bay from April 1951 to March 1959 (Table 2). All were made by tuna boat crews during routine baiting operations. Collections were made in every month except June and July. The percentage length-frequency distributions for each month's collection (1951 to 1959) are plotted in Figures 2 to 10. The distributions have been arranged to run from August of one year to May of the next.

Extended, diffuse, polymodal length-frequency distributions are immediately apparent in the figures, especially when the smallest fish are represented. The distributions from February 1952 to March 1953 (Figure 4), from September 1954 to February 1955 (Figure 6) and from September 1957 to May 1958 (Figure 9) are examples. This confusion is less apparent when the larger anchoveta are represented (e.g., September 1951 to February 1952, Figure 3). Also, in some years, the entry of juveniles into the population occurs at more than one discrete period in the year. This is different from the situation in the other areas, and some possible causes of these anomalous distributions were considered.

Some of the collections were made at Magdalena Bay, a body of water contiguous on the north with Almejas Bay, and it is conceivable that the combination of the Magdalena Bay and the Almejas Bay collections produced these discrepancies. However, separation of the samples from the two areas and comparison of the distributions showed that there were no important differences between the areas. The further possibility that spatially separated groups were being sampled was investigated by examining the single collections before they were combined to make the monthly samples. No noteworthy differences between the length-frequency distributions of the individual samples and those of the combined samples were found.

As will be shown (page 124), the spawning season in the Almejas Bay area extends from August to February, with probable periods of peak spawning activity in August-September, and in December-January. The resultant entry of the young anchoveta into the population over several months quite adequately accounts for the confusion in the distributions. Because of this, only a general analysis of the age and growth of the anchoveta in the Almejas Bay area was possible.

One or more modal groups are present in all months. However ill-defined these modal groups frequently seem, they do exhibit a serial progression which can be followed in succeeding months. These groups and progressions are perhaps best seen in the 1952-1953 collections (Figure 4) where the effects on the distributions of the two periods of peak spawning is most clear. Clarification of the age and growth of the anchoveta in these years will delineate some overall features of the age and growth of Almejas Bay.

From Figure 4, in 1952 the diffuse group of small anchoveta (53 to 84 mm.) which first appear in September can be followed through the months to March 1953 when they range in length from 107 to 125 mm. (unshaded portion of curve). These fish must have resulted from a July-August spawning and are, therefore, about 8 months old in March. A second group of small anchoveta (minimum length, 47 mm.) which can be arbitrarily separated from the December collections, can be followed through to March 1953, when they range in length from 78 to 106 mm. (shaded portion of curve, to the left). These fish must have resulted from a November-December spawning and are therefore about 4 months old in March.

The modal group of larger anchoveta (93 to 119 mm.) in the September 1952 collection can be followed through to March, when it is represented by the modal group ranging from 126 to 143 mm. (shaded portion of curve, to the right). These larger fish may either be the result of the summer spawning peak of the previous year (1951), and some 13 months old in September, or the result of the winter spawning peak and be some 9 months old in September. The summer-spawned anchoveta which are 8 months old in March range from 108 to 125 mm., so it is reasonable to assume that the modal group of fish of about the same size in the September collection are closer to 9 months of age than 13 months, and resulted from the previous winter's spawning. This group, then, is about 13 months old in March.

From this, some approximations concerning the age and growth of the anchoveta at Almejas Bay can be made. The anchoveta ranging in length from about 115 to 140 mm. (mean length, some 127 mm.) are one year old; those from about 140 to 157 mm. (mean length, about 146 mm.) are two years old; and anchoveta larger than this, three or more years old. These figures are consistent with the age and growth of the anchoveta from the other areas studied.

Using these ranges in length as general criteria of the age of the anchoveta at Almejas Bay, it was possible to assign ages to some of the more clearly defined modal groups in the distributions. These ages have been noted on the figures; when they are not shown, a mixture of age groups was assumed present and no definite ages were assigned. Because of the wide range of lengths in the age groups, a tabular presentation of the mean lengths of each age group from month to month was not prepared since it would not be meaningful.

Sexual maturity and spawning

The numbers of anchoveta examined for evidence of sexual maturity are given in Table 3 by month and year and for all years combined. Specimens were examined from all months in which collections were made. The degree of sexual maturity of the females as indicated by their gonad index class and the numbers of spent females are also provided. These latter data, for all the years combined, are presented graphically in Figure 11.

Spent females were present in the population in all months except December through the years, but not in all months of individual years. Mature female anchoveta (gonad index greater than 6) were found in the population at two periods in the year. They were taken in December

(1956 and 1958), January (1952) and February (1952), and in August (1958), as were mature male anchovetas. Mature males were also taken in January 1959. Found concurrently with the mature females in the December-January-February collections were maturing females (gonad index 3 to 6). Females in this same state of impending maturity were also taken in March, April and May 1958, probably as precursors to the August 1958 spawners. Immature females were present in the population in most months of the year, which may be a reflection of the persistence in the population of juvenile anchoveta through most months in all the years, although not in all months of an individual year.

The data available on the time of spawning and duration of the spawning season in the Almejas Bay area can be subjected to several interpretations. The several 'winter' collections and the single 'summer' collection of mature anchoveta could indicate di-annual spawning. The lack of adequate collections of adult fish in the intervening months (September, October, and November) precludes a definite conclusion However, spawning twice a year does not seem probable, since this does not happen in the other areas studied. A second possible interpretation of the data is that an extended spawning season exists, from August to February. Anchovetas smaller than 60 mm. have been collected from August to February (except November) in 1952, 1954, 1955 and 1956 (Figures 4, 6, 7 and 8), indicating the occurrence of continuous spawning. An extended anchoveta spawning season also occurs in the Gulf of Fonseca. Associated with this extended spawning season at Almejas Bay is the likelihood of two periods of peak spawning activity. Small fish (36 to 47 mm.) entered the population in August (1956) and September (1955 and 1956), and in December (1952) while reasonably adequate sampling in other months during this same period did not take fish as small as these. Also, there is a bimodality in some of the length-frequency distributions of the fish in their first year, suggesting the entrance of two somewhat discrete groups into the population. Based on the evidence available, it is probable that spawning extends from August to February in the Almejas Bay area, with periods of peak spawning activity in August-September, and in December-January.[1]

The only mature females taken ranged in length from 134 to 159 mm., but spent females ranging from 121 to 164 mm. were also collected. This size range includes anchoveta at one, two and probably three years of age. Apparently, the anchoveta at Almejas Bay, as in other regions, spawn for the first time at the end of their first year, and again in their second and third years.

Guaymas

Age and growth

Sixty-nine samples containing 8,887 anchovetas were collected at

---

[1] Subsequent to the completion of this paper, F. G. Alverson, Commission scientist, sampled sexually mature anchovetas at Almejas Bay, August 12-17, 1960.

Guaymas from April 1951 to May 1957. The number of collections made and the total number of specimens taken in each month, for all years, is shown in Table 4. All but four collections were made by tuna boat crews. Commission personnel took the August 1956 samples and one of the four collections made in September 1956. One each of the October and November collections were made by a local fisherman at Guaymas. Collections were made in all months except December. The monthly length-frequency distributions are shown for each year in Figures 12 to 18. Distributions for the several years are combined by months in Figure 19.

One or more modal groups are present in all months. These modal groups can be traced from one month to the next in most years. This serial progression and the presence of two modes is most apparent in the 1952 and 1956 collections (Figures 13 and 17). Both groups of fish are present in February 1952 and can be followed through May; the smaller group persists in June, after which no further collections were obtained. Similar modal groups appear in 1956. The dominant one representing smaller fish in February can be followed through the months to November. The other modal group of larger fish is fully manifested in April and May. Similar modal groups of small fish make their first entry in January in other years.

The smallest anchovetas which were ever taken in September and October from 1951 to 1957 were 115 and 116 mm. (Figures 15 and 17, Table 5). Since the anchoveta spawns only once annually at Guaymas, with peak activity in September and October (page 128), any fish which are found to be smaller than 115 mm. some 2 to 5 months later in November (Figure 17) and January (Figures 15 and 16) must result from spawning in the months immediately preceding. Anchovetas larger than 115 mm. at this time must be one year old or more.

Collections in November were made only in 1956. The modal group which ranges in length from 46 to 73 mm. consists of anchovetas in their first year. The group of larger fish (124 to 156 mm.) taken in the same month must be one or more years old. Anchovetas were collected in January only in 1954 and 1955. The collections contained fish ranging from 63 to 108 mm. and from 46 to 87 mm., respectively; both groups were made up of anchoveta in their first year. The February 1952 and 1956 collections contain two similarly clear-cut modal groups which range, for first year fish, from 63 to 126 mm., and for second year or older fish, from 129 to 151 mm. Equally manifest distinctions between the two age groups were apparent for most of the other months and years.

Considerably extended ranges and apparently bimodal distributions were evident in the length-frequency distributions of some of the collections of anchoveta in their first year. These were particularly noticeable in the February 1952, January and March 1954 and January 1955 collections. Examination of the composition of the monthly collections revealed in some months considerable variation among the samples, sufficient to produce either an extended size range or bimodal distribution. In other months, a single collection exhibited either of these situations. These variations are probably due to the extended spawning season and the resulting recruitment of young over a period of several months. Schooling by size, and poor sampling may also be causative factors. Even for the Gulf of Panama, where the spawning season is shorter and the sampling was better, Howard and Landa (1958) noted such anomalies. The possibility of sub-populations contributing to these effects cannot be precluded, but seems unlikely. Berdegué's (1958) detailed biometric comparison of anchoveta populations showed no evidence of sub-populations. While some differences were noted between collections from sub-areas in the Guaymas region, no consistent pattern was apparent. No sub-populations were found by Howard and Landa (1958) for the much more extended Gulf of Panama collections.

No clear-cut separation was apparent between fish in their first year and those a year or more older in May and July 1951, June 1954, and September, October and November 1956. This was due (except in November 1956) to the consolidation of the collections to form composites. The separations were apparent in the individual samples. The fish in their first year in these months were arbitrarily separated using criteria previously described.

When the data were combined by month for all the years (Figure 19) a complete (except for December) serial pattern of the growth was provided. Here, it was easier to separate out the fish older than one year than in the distributions for the individual years and months. As in the distribution curves for the individual months, the distorted ranges and bimodal distributions were present. However, it was still possible to separate out the anchoveta in their first year; these separations are noted by arrows.

The modal groups of these anchoveta in their first year can be traced from their first appearance in November at some two months of age through to October when they enter their second year. Disregarding for the moment the group of larger fish in November, it is evident from their ranges that the fish which form the second modal groups to the right in the February *et seq.* collections are serially continuous with the fish entering their second year in October. It follows that these fish, too, are in their second year. The second modal group of anchoveta in the October collections must represent anchoveta entering their third year. The extended upper limits of the range in February, March, May and September probably represent fish in their third year. Because the proportion of these fish in the populations is apparently small, no attempt was made to separate them from fish in their second year. The single November 1956 collection of the larger fish, appearing as a single mode, likely contains two year old and three year old fish. The anomaly probably resulted from biased sampling, and no attempt was made to separate out the two age groups.

The numbers, ranges and mean lengths of the anchovetas in the two age groups are given in Table 5 by month for each year and for all years combined. The anomalous November collection was recorded conveniently as fish in their second year, but no mean was struck and the data were not used in the analysis.

The mean lengths of the anchovetas for all the years combined (solid circles) and for the individual years (open circles) and the ranges in length for all the years combined are plotted in Figure 20. Since only seven fish in their second year were taken in August, no mean is shown for this sample, although the range is given. The mean lengths for all the years combined exhibit a well-defined typical growth pattern. The anchoveta at Guaymas grow rapidly from November to May (from an average length of 58 mm. to 124 mm.) but from May on, they grow slowly to a mean length of 128 mm. at the end of their first year. The rate of growth is considerably slower in the second year. At the completion of their second year in October, the fish reach a mean length of 141 mm., an increase of 13 mm.

Table 6 indicates that 77.7 per cent of the anchoveta taken in the Guaymas region from 1951 to 1957 were in their first year. The great majority of the remaining 22.3 per cent were in their second year. It was not possible to distinguish the small proportion of fish which were probably in their third year or more.

Sexual maturity and spawning

The numbers of anchovetas examined for evidence of sexual maturity and spawning are given in Table 7 by month according to year and by all years combined. Females are tabulated by stage of sexual maturity as measured by three intervals of gonad index values. Spent females are listed separately. Data for the females are also presented graphically in Figure 21.

The data are too sparse in individual years to delineate the period of spawning in any one year. Spent females are present in all months for which collections were made, except May 1956, and, therefore, their occurrence cannot be used to deduce when spawning occurs, unless it takes place all year. It is not reasonable to conclude that reproduction is continuous because the age and growth study showed recruitment of young does not take place all year, but occurs first in November and continues for perhaps three or four months.

Examination of the panel for all years' data combined in Figure 21 shows females in the most advanced stage of maturity (gonad index greater than 6) continuously from July through October with more than 30 per cent of those examined being in this condition in July and

October. In September 1956, a running ripe female was collected. During the same period, a good proportion of the females examined was in the imminently spawning stage (gonad index 3 to 6). A substantial proportion of the latter class also was present in May and June. Two per cent of the May females were in the most advanced stage and resulted from a 1951 collection; similar fish were not found in May 1956 nor in June 1954. The only years for which samples were collected in May and June were 1954 and 1956. Maturing females (gonad index less than 3) were most prevalent from April through July and gradually disappeared thereafter. Some few such fish were also found prior to April.

Spawning probably occurs in the Guaymas region mainly from July through October with peak spawning in September and October and with minor activity sometimes taking place prior to July. Spawning in some years continues into November and December, as is indicated by the presence of small anchoveta in the January, February and March collections (Table 6). The data are too sparse to detect what variation, if any, takes place from year to year and whether or not there are differences in the sub-areas of the Guaymas region. Collections of mature females in the Yaqui River area but not in the Guaymas harbor area in July 1951 indicate that spawning may be earlier in the Yaqui River area.

The length-frequency distribution of all the sexually advanced (gonad index 6 or greater) females taken at Guaymas in October is compared in Figure 27 with the length-frequency distribution of all the anchoveta taken at Guaymas in October. This latter distribution is made up of modal groups of one year old and two year old fish (page 126). The distributions coincide which indicates that the anchoveta at Guaymas spawn for the first time at one year of age, and again at two years.

Ahome Point

Age and growth

Forty-three collections consisting of 4,996 anchovetas were made in the vicinity of Ahome Point from April 1951 to August 1957 (Table 8). All collections were made from September to December in any of the years. The length-frequency distributions for each month's collections are shown for each year in Figures 23 to 28. The distributions for all years combined are plotted in Figure 29.

One or more modal groups are present in all of the distributions. These modal groups can be followed by month as they move to the right in most years. The serial progression and the presence of two modal groups are most apparent in 1951 and 1957 (Figures 23 and 28). In 1951, the dominant modal group which first appears in April can readily be followed through successive months to August. In July and August, distinct second modal groups of larger anchovetas are present. Less prominent but equally definite precursory modal groups of these larger anchovetas are evident as extensions to the right of the length-frequency distributions of the first modal group in the preceding three months. Similarly, the extended modal group which appears in January 1957 (Figure 28) is apparent through May. The second modal group which appears in February can be followed through August. Data for other years are sparse except in 1956 where two modes are discernible in February and March.

The anchoveta spawns once annually at Ahome Point; peak of reproductive activity is in August (page 130). The smallest fish taken in an August collection was 118 mm. (Figures 23, 27 and 28; Table 9). Any fish of lengths less than 118 mm, which appear in the population in January must necessarily result from the summer spawning, and must be in their first year. Similarly, fish larger than 118 mm. are one or more years old. (The reader is reminded that no collections were made in September through December). These age groups were discernible in all the collections in which they appeared. Separation of the first year fish is indicated by arrows in the figures. Their numbers, ranges and mean lengths by month for each year and for all years combined are given in Table 9.

Available evidence suggests that anchovetas at Ahome Point spawn once annually and that reproduction probably occurs over about the same period from June to August each year (see page 130). Combining all the length-frequency data by month for all years is probably well-justified to obtain a better picture of growth and the number of age groups. Figure 29 and Table 9 provide this picture. Two distinct age groups were present in most months. They correspond to those fish in their first year and those in their second or more. There is an obvious break between the two groups except in May and August. Here, the two groups were separated arbitrarily on the basis of maximum length of the fish contributing to the younger age group in preceding and succeeding months.

The modal group consisting of the larger fish apparently is predominantly of one age group. There is little to suggest, either from the combined data or for the individual years, that more than one age group is present. There is a possibility, however, that a few fish are one year older than the others in this group. These are the few that appear as isolated individuals at the upper extension of the length ranges in certain months. Included are the anchovetas at 157, 159 and 160 mm. in January 1952, and 160 and 162 mm. in March 1957. For all practical purposes, though, the Ahome Point population, as indicated by the available samples consists only of two age groups. The numbers, ranges and mean lengths of this second group by month for each year and for all years combined are given in Table 9.

The monthly mean lengths for all the years combined (solid circles) and for individual years (open circles) and the ranges in length for all the years combined are plotted in Figure 30 to give a picture of the growth rate. Growth is rapid from January to March (91 mm. to 117 mm.) but thereafter it is slower. At the end of the first year, these fish reach a length of about 130 mm.; a year later, they approach 150 mm.

About 80 per cent of the anchovetas sampled at Ahome Point by tuna fishermen between 1951 and 1957 were in their first year (Table 6).

Sexual maturity and spawning

Anchovetas from Ahome Point were examined for evidence of sexual maturity for all the months in which collections were made. The numbers examined according to time of capture are given in Table 10, for each month's collections and for all years' collections combined. The degree of sexual maturity of the females as indicated by their gonad index and the number of spent females are recorded. The latter data, by month for all the years combined, are presented graphically in Figure 31.

As at Guaymas, spent females were present in all months for which collections were available. Again, their presence is not an indication of the time of spawning. The sampling was such that it was not possible to use the data for individual years to delineate the period of reproduction (Table 10). Best coverage was in 1951 when collections were available from April through August. Females in advanced stages of sexual maturity (gonad index greater than 6) were found in June, July and August only. Females of similar condition were also found in the same months of other years in which collections were made except August 1957 when the five females studied were found spent. Generally, advanced females were dominant over other categories in July and August. The composite presentation in Figure 31 provides the best over-all picture. The situation is very similar to that in Guaymas through August but, unfortunately, there were no Ahome collections for September and October. Since there was no apparent decrease in the proportion of sexually advanced females in August over July, it is reasonable to conclude that spawning continues into September and perhaps even as long as at Guaymas (to December).

The length-frequency distribution of the 53 mature females (gonad index 6 or greater) taken in August of all years at Ahome Point has been plotted in Figure 22. Superimposed is the length-frequency distribution of all the anchovetas taken in August in all the years. Both distributions coincide closely, and the mature females are represented in both age groups of the population. Apparently the anchoveta at Ahome Point spawn for the first time in their first year and again in their second.

Banderas Bay

Age and growth

Twenty-two collections, consisting of 2,211 anchovetas, were made at Banderas Bay from May 1952 to April 1956 (Table 11). All collections were made in the first five months of the year by crew members of tuna boats.

Because the collections were scattered through the years, the length-frequency distributions for each month's collections in each year are not plotted, but the distributions for all the months combined are (Figure 32). The size ranges and mean lengths of each month's collections (by year classes) and for all the collections combined are given in Table 12.

Inspection of Figure 32 shows the presence of two distinct modal groups. A modal group of smaller fish is present in the population in March, April and May; a second modal group of larger fish is present in January, February, March and April. Collections containing both size groups were made only in March (1954 and 1956) and April (1954 and 1955).

The smallest fish taken in January and February were 98 and 102 mm. Modal groups made up of anchovetas smaller than this were taken in March *et seq.*, indicating the probable entry into the population of a new age group. The study of sexual maturity (page 132) suggests indirectly that spawning at Banderas Bay occurs in the later months of the year; the appearance of small anchoveta in the early months of the year is consistent with this. Also, the mean length of the fish in this group, some 87 mm., indicates they are about 3 months old, based on growth rates in other areas. Fish contributing to the modal group of smaller fish are apparently in their first year.

Because collections from January to May only are available, it is not possible to follow sequentially the growth of the fish until they form the second modal group in the following year. Mean length differences between 3 and 15 months old anchovetas in other areas are from 31 to 49 mm. The difference in mean length between anchovetas in the two modal groups taken in March at Banderas Bay is 38 mm., which is within the range of the differences in the other areas. It is probable that the fish forming the second modal group are in their second year.

The evidence available, though admittedly inadequate, suggests that the anchoveta in Banderas Bay are considerably smaller than anchovetas of the same age in other areas. The fish taken in January 1956 are assumed to be at least 13 months old. The mean length of the anchovetas in this collection is 115 mm. The mean length of the fish at this age in the other areas is about 125 to 130 mm. Comparably small fish contributed to the modes representing fish in their second year in the 1954 and 1955 collections, indicating that the smaller size is not peculiar to the 1956 collections.

About 84 per cent of the anchovetas taken in Banderas Bay were in their first year (Table 6).

Sexual maturity and spawning

Anchoveta ranging in length from 90 to 130 mm. were examined for evidence of sexual maturity. The fish examined included specimens from both age classes, and were from all months in which collections were made. All the fish examined were immature; it was not possible even to determine their sex. No spent fish were found.

Spawning at Banderas Bay must occur sometime from June to December. The appearance of the modal group of smaller fish in March suggests that the spawning period is probably closer to December than to June. The presence of a group of smaller fish of the same size in the same months in each of the four years in which collections were taken indicates a consistency in the annual time of spawning.

Gulf of Fonseca

Age and growth

Twenty-seven collections consisting of 2,588 anchovetas were made in the Gulf of Fonseca from May 1951 to September 1955 (Table 13). All collections were made by tuna boat crews. No collections were made from October to March in any of the years, except for a single collection in December 1951.

The length-frequency distributions for each month of each year are given in Figures 33 to 36. The collections noted under July-August 1951 were made on July 30, August 2 and August 4. The data for all the years are combined in Figure 37. The collections for July and August for all the years are combined so that the July-August 1951 sample might be included.

The figures show one or more modal groups which may be followed through most months each year. In 1951 (Figure 33) the modal group which appears in May can be followed through to December. Another modal group of larger fish is apparent in the August collection. The few smaller fish taken in May, June and July-August probably represent a third modal group. The modal group of smaller fish first appearing in April 1952 (Figure 34) can be followed through June. In June, two more modal groups of larger fish are present. These reappear in the August collection. One modal group can be seen in July, August and September 1954 (Figure 35); some smaller fish in August and September likely represent another modal group. In 1955 (Figure 36), three modal groups are present in June. The two modal groups in September probably represent the two groups of larger fish in June. However, the number of fish involved is small.

While the separation into three modal groups is clear, the designation of age groups is less so. This is mainly because no collections of juvenile fish were taken, although they might be expected to be in the population after the peak period of spawning in September and later (page 134). However, when all years' data except 1952 are combined and plotted (Figure 37), some conclusions as to the age groups may be drawn. The length-frequency distributions of the 1952 collections are plotted separately, however, in Figure 37 (dotted lines) because, in the April, May and June collections, they differed from those in all other years. However, the analysis of the age groups is based on the combination of data for all years, including 1952.

The anchoveta spawns only once annually at the Gulf of Fonseca; the peak of reproductive activity is in September and probably later. The smallest anchoveta taken in September was 129 mm.; in December, 128 mm. Any fish smaller than this which appear in the population after this probably resulted from this spawning and are in their first year. Thus, all the April 1952 and most of the May and June 1952 collections consist of fish in their first year. Fish in the first modal group of approximately the same size range in the same months in the other years likely are also in their first year. Separation of the first year fish is indicated by arrows in the figures. Their numbers, ranges and mean lengths by month for each year and for all years combined are given in Table 14. Only in 1952 were substantial numbers of anchovetas in their first year taken.

The limited number of months for which collections are available precludes tracing the progression of the first modal group until it forms the second modal group a year later when the incoming year class makes its appearance. It can only be assumed, in view of similar situations in other areas, that the larger fish comprising the second modal group are in their second year. Similar limitations apply to the designation of age of fish in the third modal group. These are assumed to be in their third year. Separation of these two age groups is noted in the figures by arrows. The numbers, ranges and mean lengths of these fish by month for each year and for all years combined are given in Table 14. (In September and December, some smaller fish have been included with those in their second year although their size suggests that they are more likely in their first year. However, it was not possible to separate them, because of the configuration of the length-frequency distributions. In Figure 22, where the length-frequency distribution of the mature females taken in September is plotted, a break appears at 137 mm. It is probable that this is closer to the true upper range of length of fish in their first year in that month. It has been so marked in Figure 22).

The monthly mean lengths for all the years combined (solid circles) and for individual years (open circles) and the ranges in length for all the years combined are plotted in Figure 38 to give a picture of the growth rate. The points at September (fish in their first year) and December (fish in their fourth year) represent single fish. Growth is apparently rapid in the first year to July and August but thereafter it is slower. At the end of their first year, the mean length is probably 125 to 130 mm.; a year later, 140 to 145 mm.; and, at the end of their third year, some 160 mm.

About 55 per cent of the anchoveta taken at the Gulf of Fonseca were in their second year; about 12 per cent were in their third year (Table 6). This represents a greater proportion of two and three year old fish than were taken at any other area except for two year old fish at Colombia.

Sexual maturity and spawning

The numbers of anchovetas from the Gulf of Fonseca examined for evidence of sexual maturity are given in Table 15, by year and month collected, and for all years combined. The degree of maturity of the females as indicated by the gonad index and the number of spent females is also included. The latter data, for individual years and for all years combined, are shown in Figure 39.

The sexual maturity and spawning of the anchoveta in the Gulf of Fonseca was investigated by use of the gonad index. In addition, ova were measured. The data were used to test the validity of the use of the gonad index for anchoveta from a region other than the Gulf of Panama. Howard and Landa (1958) showed that the anchoveta in the Gulf of Panama spawned only one batch of eggs in a season. The ova measurement data from the Gulf of Fonseca anchovetas were also analyzed to determine if this held for anchoveta from other areas.

Time of spawning

Spent females were present in all the months that collections were made, except July 1951 (Figure 39). Their occurrence cannot be used to deduce when spawning occurs. Mature females are present in the September collections (1954 and 1955). Maturing females are present in June (1955), July (1951) and August (1951 and 1954). Fish with immature but discernible ovaries are present in all of these months and in May 1951. Examination of the ovaries of the 16 spent females in December 1951 indicates that some may have spawned recently. One ovary was considered to be 'running ripe'; others were only partly spent. Four of the males examined were mature.

Spawning occurs in the Gulf of Fonseca from September probably through December, with some activity taking place prior to September. As noted in the discussion of age and growth, there is no corroborative evidence of the appearance of small fish two or three months later because of the lack of collections in October and November and the lone sample in December which consisted of larger fish. The presence of the mature females in the population leaves little doubt as to the peak period of spawning, or its approachment. The lack of data in the immediately succeeding months does not permit a firm determination of how long thereafter it may continue.

The length-frequency distribution of all the sexually mature (gonad index 6 or more) females taken at the Gulf of Fonseca in September is compared in Figure 22 with the length-frequency distribution of all anchovetas taken at the Gulf of Fonseca in September. This latter distribution is made up of modal groups of one, two and three year old fish. Both distributions coincide. The anchoveta from the Gulf of Fonseca spawn for the first time at one year of age, again at two, and again at three.

Frequency of spawning in a season

From the study of succeeding batches of maturing eggs in an ovary, it is possible to determine the frequency of spawning in a season. When the length-frequency distributions of the egg measurements of all the fish grouped according to the position of the last mode in the length-frequency distribution of each are plotted (Figure 40), a composite picture showing the growth of the ova to maturity is presented. Ten equal length intervals for the position of the last mode were selected between 0.20 and 0.69 mm. The numbers of fish included in each group are shown. No ovaries with the largest modal group of eggs at 0.20-0.24 mm. or at 0.30-0.34 mm. were found.

The uppermost panel in Figure 40 depicts the length-frequency distribution of eggs from the most immature ovaries. A single mode of large eggs becomes apparent as the ovary matures (succeeding panels). The progression to the right of this group indicates the development of these eggs to maturity. No second modal group of smaller eggs develops as the ovary matures, indicating that another batch of eggs does not replace the first. It is clear that the female anchovetas in the Gulf of Fonseca spawn only one batch of eggs in a season.

Figure 40 is essentially similar to Figure 11 of Howard and Landa (1958) for the anchoveta in the Gulf of Panama. Apparently, the female anchoveta in the Gulf of Fonseca are not different from those in the Gulf of Panama in that they spawn only one batch of eggs in a spawning period. This probably holds for the anchoveta from the other regions as well.

Relation of gonad index to sexual maturity

The mean lengths of eggs 0.20 mm. or longer are plotted against the respective gonad index of 59 female anchovetas from all age classes and years (Figure 41). A linear mean square regression line is fitted to the data ($y = 0.2984 + 0.0248\ x$). The F test showed no significant departure from linearity at either the one per cent or five per cent level.

Since the anchoveta must spawn when the egg reaches a maximum size, the gonad index (linearly related as it is to egg size) is a useful indication of the degree of sexual maturity. Howard and Landa (1958) also found such a relationship for anchoveta from the Gulf of Panama. The gonad index appears a valid indicator of the degree of sexual maturity of female anchoveta.

Colombia

Age and growth

Twenty-five samples consisting of 1,709 anchovetas were collected along the coast from Buenaventura to Tumaco, Colombia from July 1951 to August 1959 (Table 16). The collections from 1951 through 1955 were made by tuna boat crews. The 1957 collections were made by Commission personnel, using a trawl net. The 1958 and 1959 collections were taken near Tumaco with lampara, cast and trawl nets, by local fishermen.

Because of the small size of some of the collections and because they were collected sporadically, the length-frequency distributions of the individual months' collections are not plotted. However, the data for the collections are given (by age group) in Table 17. The length-frequency distributions for all years combined are plotted in Figure 44 from data also provided in Table 17.

One modal group of fish with a mean length of 127 mm. was present in the February collections. This group can be followed in March and April (Figure 42). The modal group in the small August collection represents a slight further progression of this group.

Not including (for the moment) the 14 small (mean length, 41 mm.) anchoveta taken in April 1959, a second modal group of fish smaller than those taken in February *et seq.* appeared in the April collections.

The extended length range of the June collection indicates the inclusion of both modal groups. The dividing point between these groups was set at 137 mm. Other divisions between the two groups of fish are noted by the arrows (Figure 42).

The smallest fish found in the February collections was 107 mm. The anchoveta spawns once annually and, in the Colombia region, usually in the latter months of the year (page 137). Thus, anchoveta taken three to four months later and smaller than 107 mm. must have resulted from the previous spawning. The four smaller fish in March and all the fish below 109 mm. taken in April must be in their first year.

Although there are some gaps in the collections, it is possible to follow sequentially the modal group containing fish in their first year as it progresses to the right to form the second modal group a year later when the incoming year class makes its appearance.

In April 1959 a large collection of juvenile thread herring *(Opisthonema libertate)* was taken at Tumaco. Found in this collection were 14 juvenile anchoveta (range 27 to 54 mm.), smaller than anchoveta taken previously off Colombia in March or April. These small anchoveta must have resulted from a late spawning in the Colombia area in 1959. Anchoveta of this size were not taken in April in any of the other years collections were made.

The numbers, ranges and mean lengths of the anchovetas in the two age groups are given in Table 17 by month for each year, and for all years combined. Fish at the end of their first year are about 126 mm. long; at the end of their second year, about 142 mm. long.

From Table 6 about 59 per cent of the fish collected off Colombia were in their second year. This proportion is higher than at any other area.

Sexual maturity and spawning

Anchovetas from Colombia were examined for evidence of sexual maturity for all months in which collections were made. The numbers examined according to time of capture are given in Table 18, for each month's collections and for all years' collections combined. The degree of sexual maturity of the females as indicated by their gonad index and the number of spent females are recorded. The latter data, by month for all the years combined, are presented graphically in Figure 43.

A high percentage of immature but identifiable females occurred in June and July. By October and November, spawning was in progress. Sixty-seven per cent of the females examined were in an advanced state of maturity; less sexually advanced but obviously maturing females were also taken then.[1] Spawning was still in progress in February; 42 per cent of the females were sexually mature, and less mature but maturing females were also taken. By March and April all but one of the 46 females examined were spent. Collections of small anchoveta (27 to 109 mm.) in their first year were made in March and April. Spawning off Colombia likely starts in October and continues through to February. The peak period of spawning cannot be determined from these data.

The range in length of the mature females was 120 to 134 mm., which included anchoveta in both age groups. The anchoveta at Colombia spawn for the first time in their first year and again in their second.

Ecuador-Peru

Age and growth

Thirty-one collections consisting of 4,238 anchovetas were made along the coast of Ecuador-Peru from September 1951 to April 1960 (Table 19). Collections in 1951 and 1952 were made only in the Gulf of Guayaquil, during routine baiting operations of tuna boats. In 1952, the Gulf of Guayaquil was closed to baiting and no collections were made until 1958 when further collections were made by Commission personnel. The latter were made at Manta, Ecuador and from the Gulf of Guayaquil. Since 1958, collections have also been made at Los Organos, Punta Sal and Paita, Peru, with cast nets, trawl nets and beach seines. Collections were made in all months except February and July.

Because of the paucity of the data, the monthly collections for all years and areas were combined and the length-frequency distributions plotted (Figure 44). The sources of the collections are given on the figure; the areas noted in italics correspond to the shaded portion of the distributions. No pre-eminent differences in distribution obtained among the various areas, so the combination seems valid; any discrepancies are likely due to the extended spawning period (page 139). Individual monthly length-frequency distributions were not plotted but the pertinent data for each month's collections are given in Table 20.

---

[1] A collection made at Tumaco from September to November 1959 contained sexually mature male and female anchoveta, offering further evidence concerning the time of spawning. These data are not included in the tables or figures.

One or more modal groups are present in all the distributions. The modal groups can be followed as they move to the right in most months. The dominant modal group of smaller anchoveta, which first appears in March, can readily be followed through successive months to January. In March, April, December and January, distinct second modal groups of larger anchovetas are present. Some larger fish in the September-October and the November collections also represent this second modal group. Further, in March, the extended distribution to the right indicates the continued presence of these larger fish, which form a third modal group with the entry of the incoming modal group of the smallest fish.

The anchoveta spawns once annually in this area; peak of reproductive activity is in December and January (page 139). The smallest fish taken in December and January collections were 102 and 105 mm. (Figure 44, Table 20). Any fish of lengths less than this which appear in the population in March and April must result from this spawning. Similarly, fish larger than this are one or more years old. (In the March collections, some fish ranging to 110 mm. were taken, and, in the March, April and May collections, some bimodality in the distributions of the smaller fish is evident; these anomalies may be attributed to an extended spawning season in the area. All these anchoveta were regarded as in their first year). The age groups were discernible in all the collections in which they appeared. Separation of the first year fish is noted by arrows in Figure 44. Their numbers, ranges, and mean lengths by month for each year and for all years combined are given in Table 20.

The modal groups consisting of the larger fish are predominantly of one age group, except in March when the fish larger than 134 mm. probably represent another age group. The anchoveta ranging from 121 to 134 mm. in March apparently have entered their second year because they are serially continuous with the predominant modal group of fish ending their first year in January. The modal group of the largest anchoveta (134 to 147 mm.) in March is continuous with the modal group of anchoveta completing their second year in January and apparently are in their third year. The numbers, ranges, and mean lengths of these fish in their second and third years are given in Table 20 by month, for each year and for all years combined.

The monthly mean lengths for all the years combined (solid circles) and for the individual years (open circles) and the ranges in length for all the years combined are plotted in Figure 45 to give an estimate of the growth rate. Growth is most rapid from March to September during the first year of life. At the end of their first year, these fish reach a length of about 118 mm.; a year later, they attain a length of some 141 mm.

About 90 per cent of the anchoveta sampled at Ecuador-Peru were in their first year (Table 6). The proportion of the collections consisting of first year fish is slightly greater here than at any of the other areas.

Sexual maturity and spawning

Only the 1951-1952 collections from the Gulf of Guayaquil were available for examination for evidence of sexual maturity.[1] Because of the uniformity in size of the various collections from the Ecuador-Peru region, the Gulf of Guayaquil collections probably can be considered to be rather representative.

The numbers of anchovetas from the Gulf of Guayaquil examined for sexual maturity are given in Table 21 by month and year. All the collections were examined. Fish taken only in the months noted in the Table (September to January) had discernible gonads except for the November samples where all the fish examined were immature except for one spent female. All the other collections, from April to August, consisted of immature anchoveta.

No mature (gonad index greater than 6) females were found in the collections until December when three of the 38 females examined were in near-spawning condition. In January, 4 of the 13 females examined were in a similar state. Also present in these two months were groups of females approaching maturity, with gonad indices in the 3-6 class. Females in this class were also taken in the September-October collections. Spent females were found in all of the collections after September-October. Concurrent with this increasing level of maturity was a decline in the number of immature females (gonad index less than 3) from 66 in September-October to 13 in December and none in January.

The sizes of the sexually immature anchoveta examined from the November collection indicated that they were completing their first year. As they matured, this group of fish likely contributed to the December and January spawning population, and may have contributed to continued spawning into February and March. If this were the case, and if spawning is extended into February and March of every year, the presence of the small fish in the months of April and May in both 1958 and 1959 can be accounted for.

However, the data definitely indicate a gradual increase in the maturity of the anchoveta in the Gulf of Guayaquil, culminating in spawning in December and January. Spawning in this area probably extends further into the year (into February and possibly March) than our collections indicate, on the basis of the immature, almost-one-year-old fish in November, the immature females in the populations in January, and the small fish in the population in April and May.[2]

There were only seven females in all the collections with gonad indices six or greater. These sexually ripe females ranged in length from 117 to 145 mm. The individuals, therefore, were representative of both age groups—those completing their first year and those completing their second year of life.

---

[1] Since completion of the manuscript, the 1959-1960 collections became available for examination for evidence of sexual maturity. The results of the examination are in accord with conclusions already reached, using only the Gulf of Guayaquil material.

[2] Mature fish were taken in the March 1960 collection.

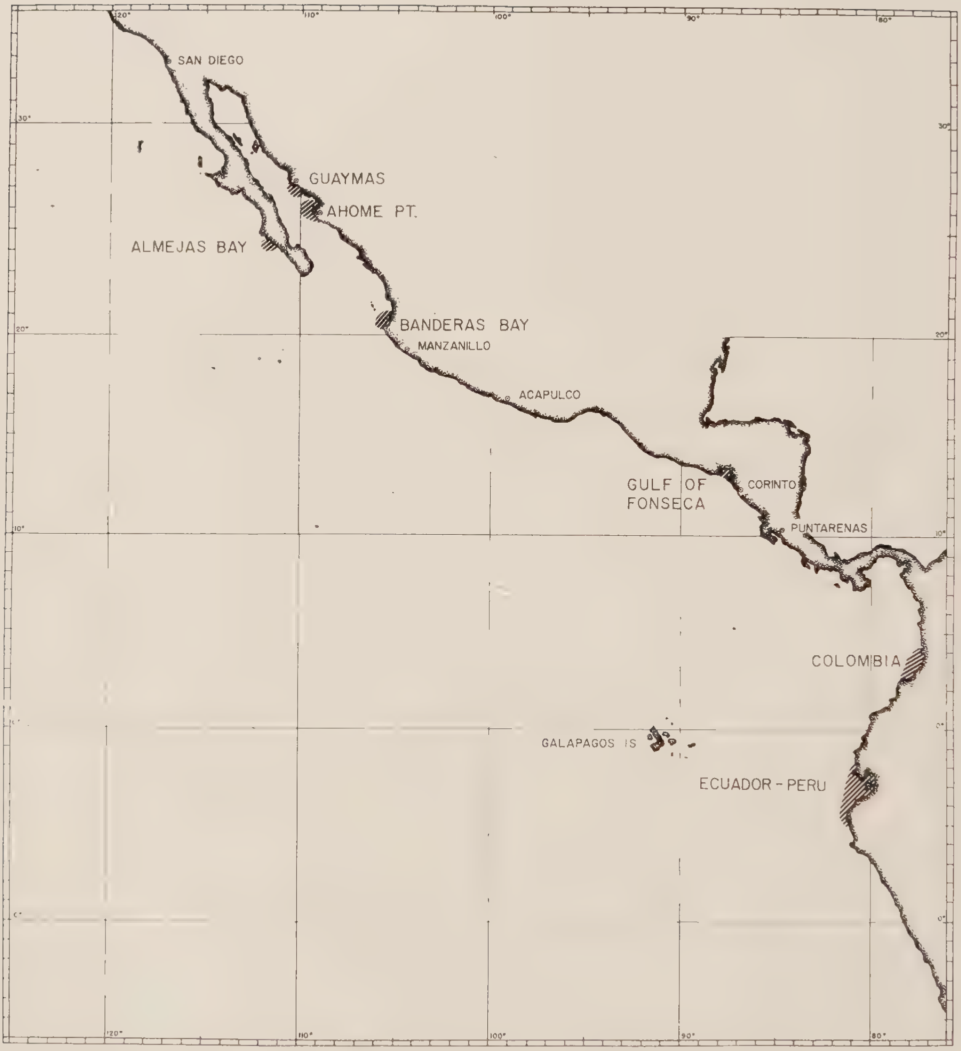

SAN DIEGO
GUAYMAS
AHOME PT.
ALMEJAS BAY
BANDERAS BAY
MANZANILLO
ACAPULCO
GULF OF FONSECA
CORINTO
PUNTARENAS
COLOMBIA
GALAPAGOS IS
ECUADOR - PERU
120°
110°
100°
90°
80°
30°
20°
10°
0°

Figure 1. Chart of the Eastern Pacific region showing the seven localities from which anchovetas were collected for study.

Figura 1. Mapa de la región del Pacífico Oriental que muestra las siete localidades en donde se recolectaron anchovetas para el estudio.

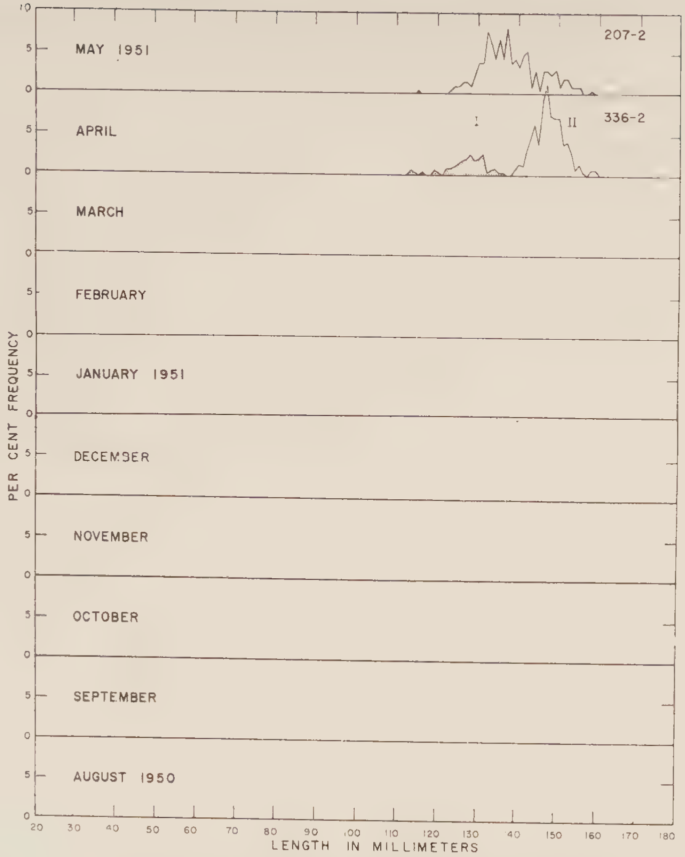


Figure 2. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almeja Bay in April and May, 1951.

Figura 2. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas en abril y mayo de 1951.

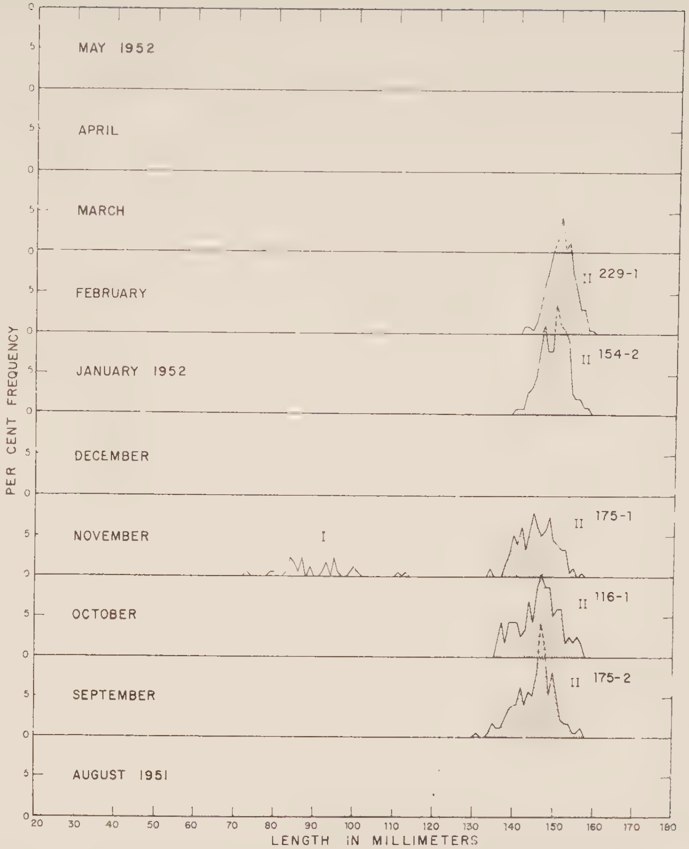


Figure 3. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from September 1951 through February 1952.

Figura 3. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de septiembre de 1951 a febrero de 1952.

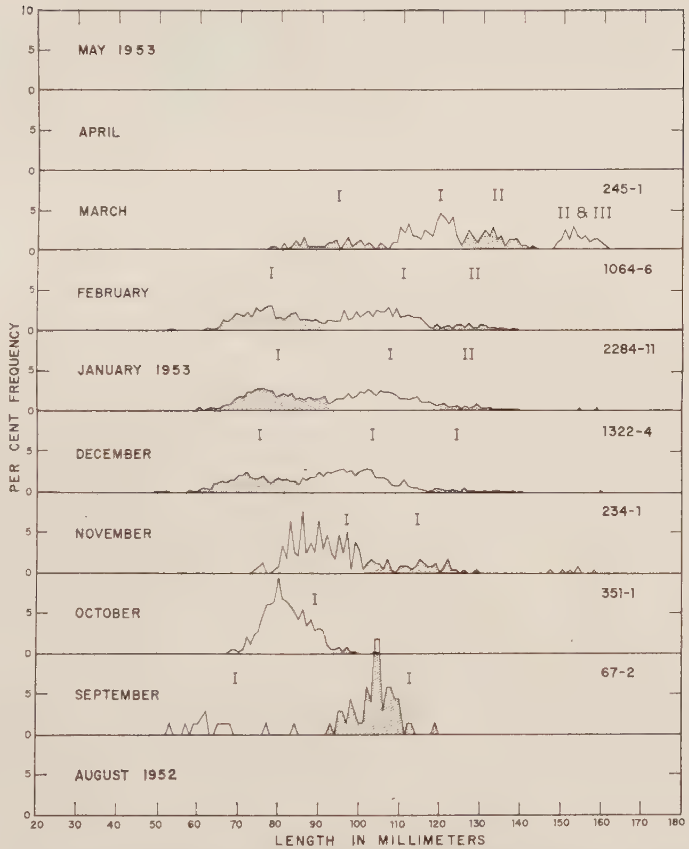


Figure 4. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from September 1952 through March 1953.

Figura 4. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de septiembre de 1952 a marzo de 1953.

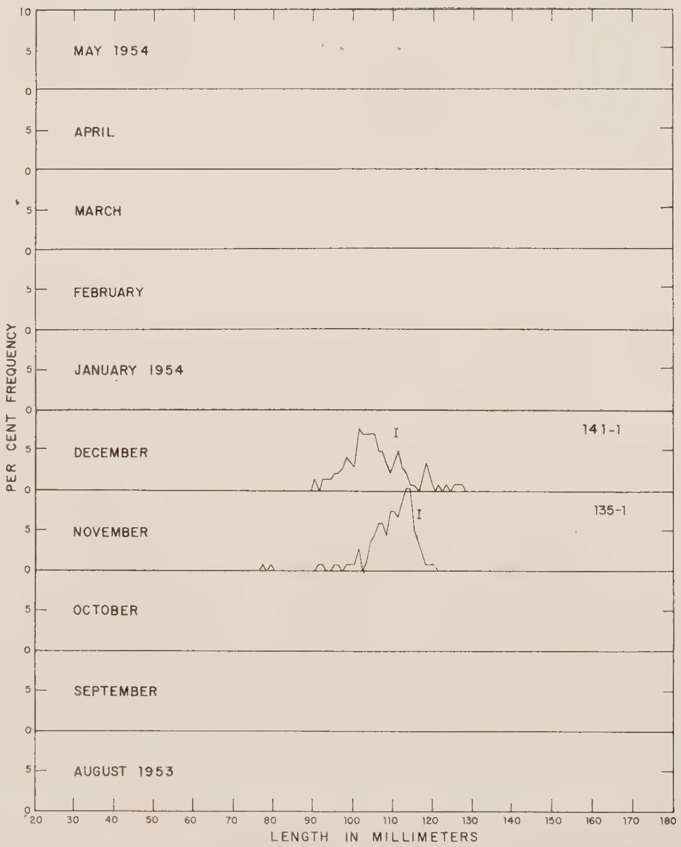


Figure 5. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay in November and December, 1953.

Figura 5. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas en noviembre y diciembre de 1953.

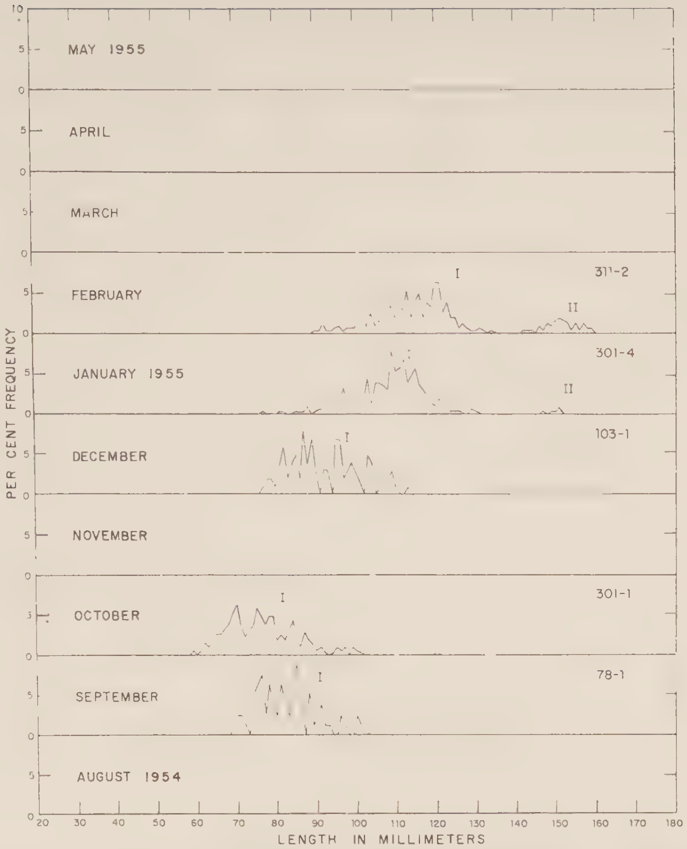


Figure 6. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from September 1954 through February 1955.

Figura 6. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de septiembre de 1954 a febrero de 1955.

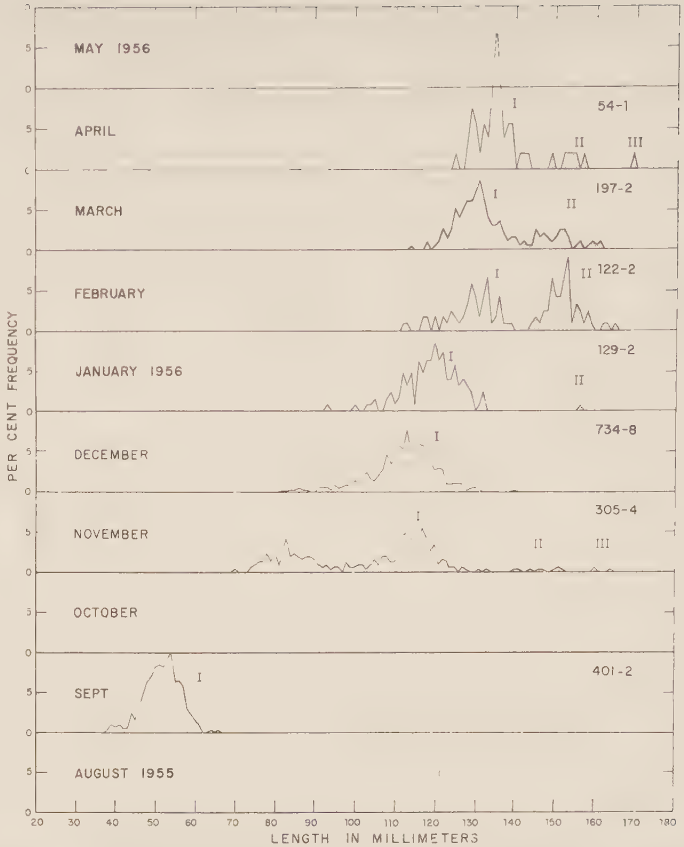


Figure 7. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from September 1955 through April 1956.

Figura 7. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de septiembre de 1955 a abril de 1956.

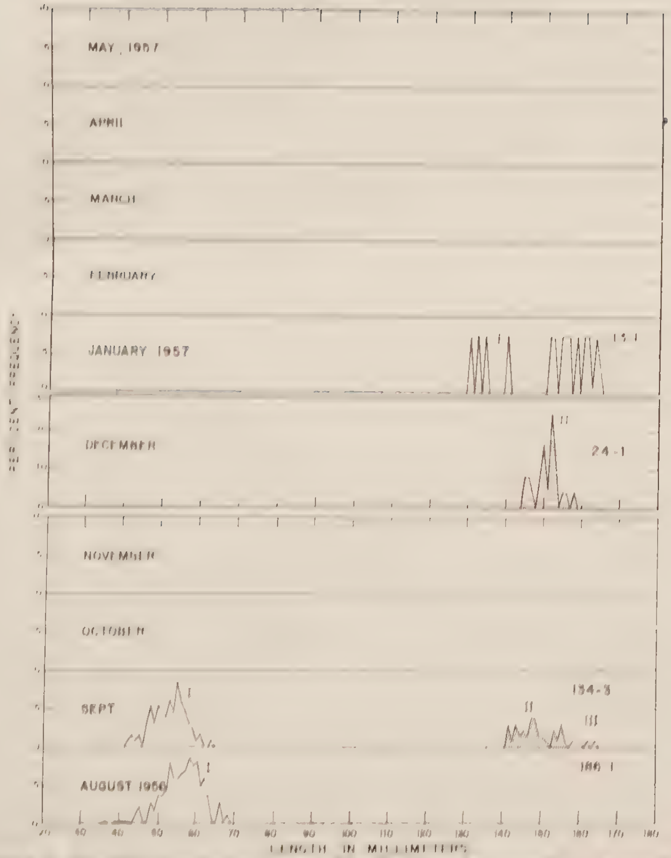


Figure 8. Monthly length frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from August 1956 through January 1957.

Figura 8. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de agosto de 1956 a enero de 1957.

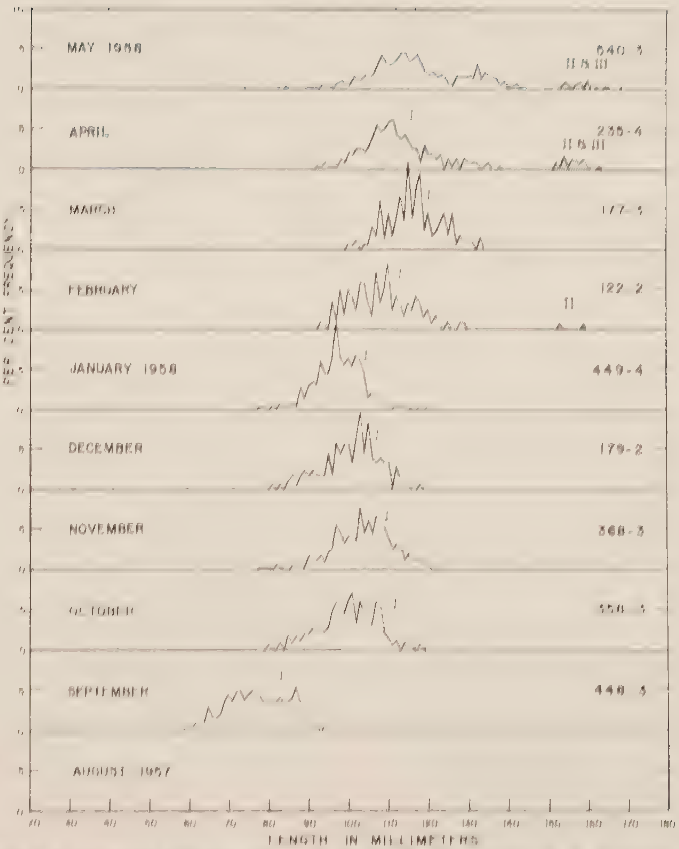


Figure 9. Monthly length frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from September 1957 through May 1958.

Figura 9. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de septiembre de 1957 a mayo de 1958.

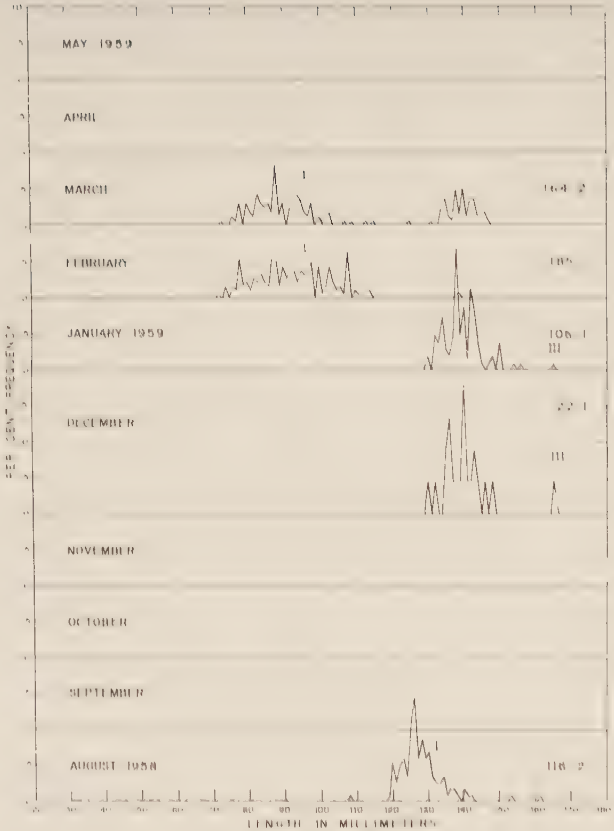


Figure 10. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Almejas Bay from August 1958 through March 1959.

Figura 10. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en la Bahía de Almejas de agosto de 1958 a marzo de 1959.

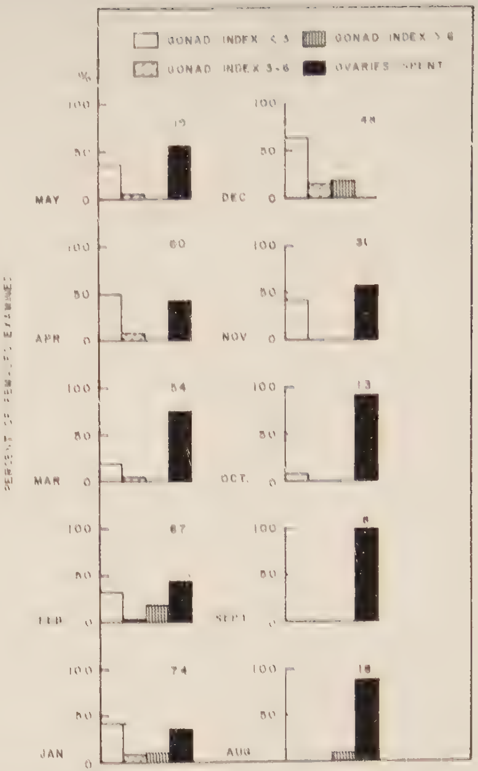


Figure 11. Condition of the ovaries of anchovetas as measured by the gonad index, combining all collections made at Almejas Bay from April 1951 through March 1959. Monthly distributions are given in per cent. Numbers in panels indicate number of females examined.

Figura 11. Condición de los ovarios de las anchovetas según la medida del índice de gónadas, combinando todas las recolecciones hechas en la Bahía de Almejas de abril de 1951 a marzo de 1959. Las distribuciones mensuales se dan en porcentajes. Los números en cada panel indican el número de hembras examinadas.

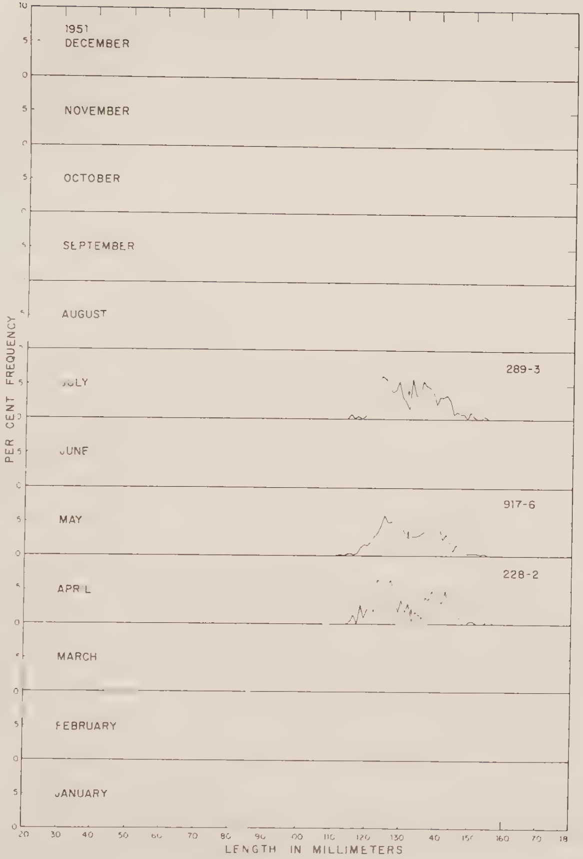


Figure 12. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1951.

Figura 12. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1951.

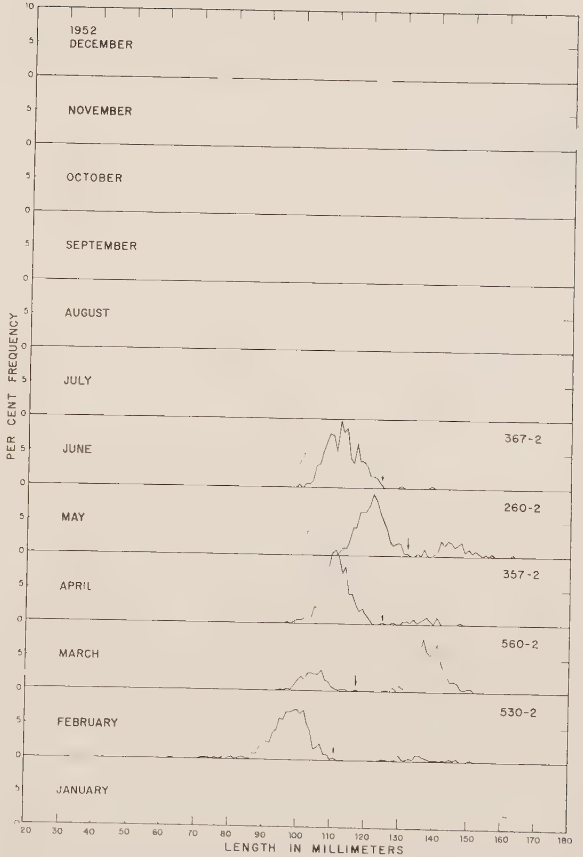


Figure 13. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1952.

Figura 13. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1952.

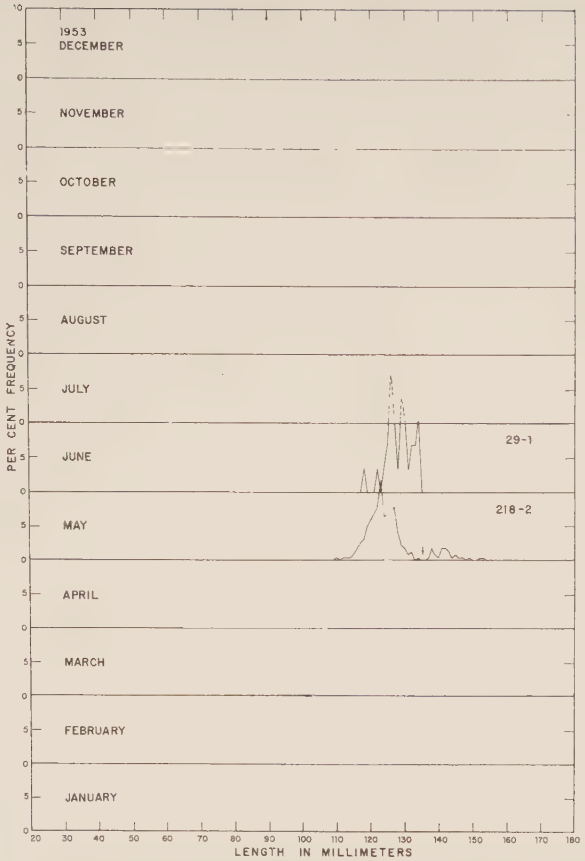


Figure 14. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1953.

Figura 14. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1953.

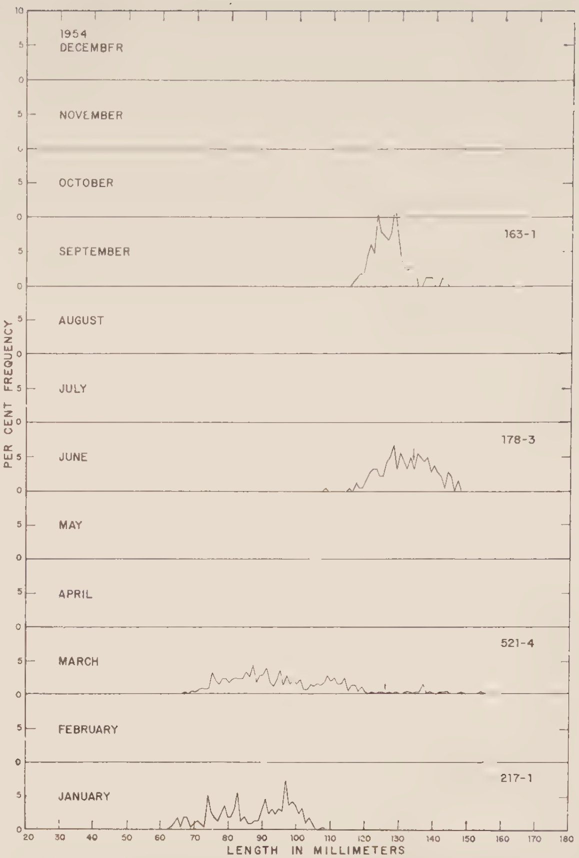


Figure 15. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1954.

Figura 15. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1954.

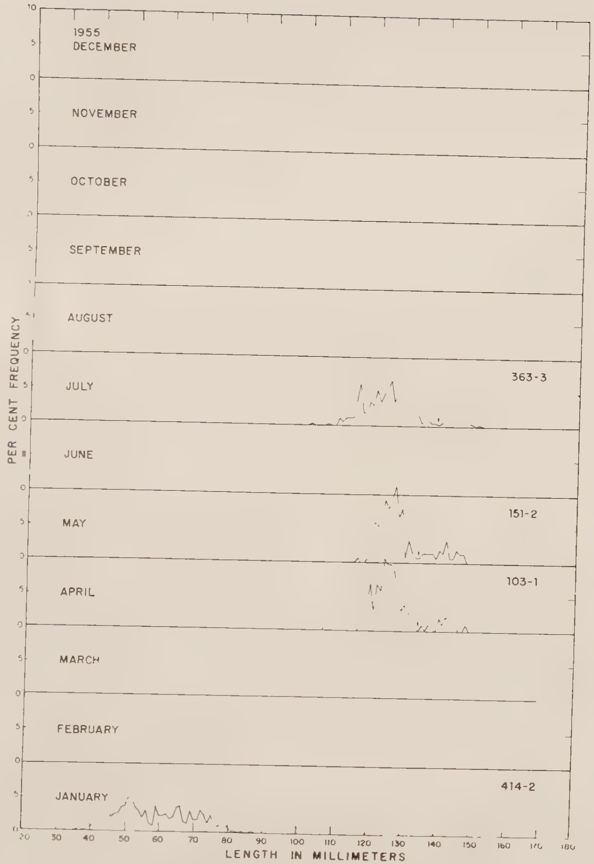


Figure 16. Monthly length-frequency distributions expressed in percent- of anchovetas collected at Guaymas in 1955.

Figura 16. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1955.

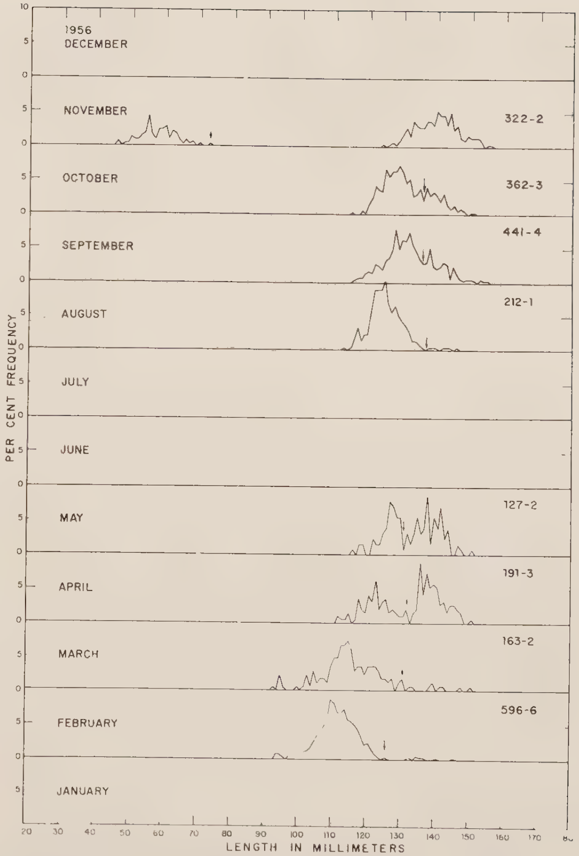


Figure 17. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1956.

Figure 17. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1956.

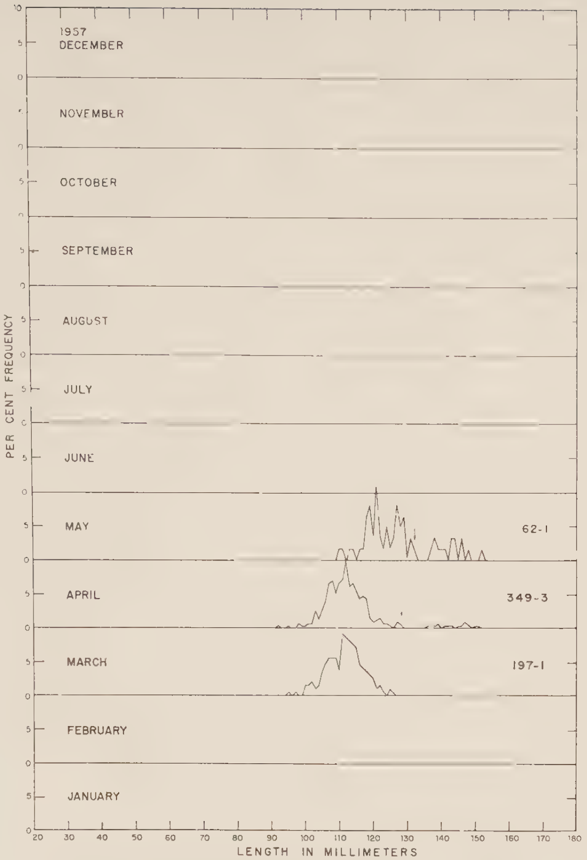


Figure 18. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Guaymas in 1957.

Figura 18. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Guaymas en 1957.

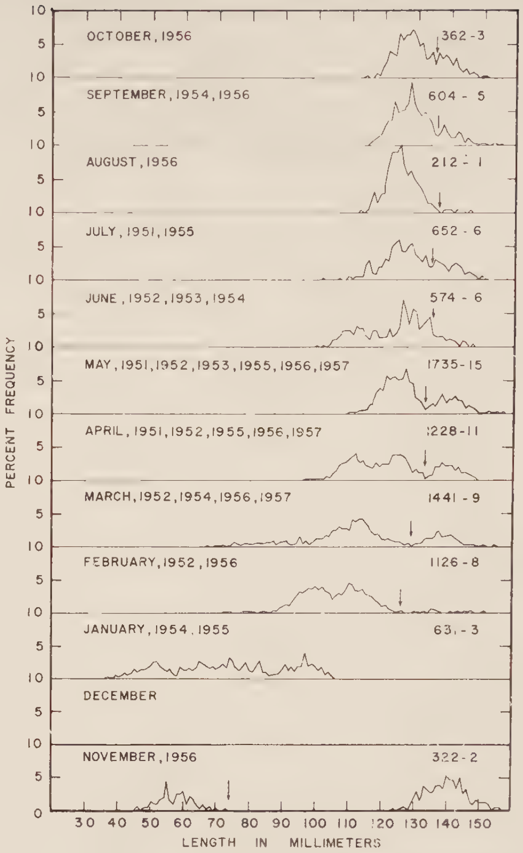


Figure 19. Monthly length-frequency distributions, expressed in percentage, combining all collections of anchovetas made at Guaymas from 1951 through 1957.

Figura 19. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones de anchovetas hechas en Guaymas de 1951 a 1957.

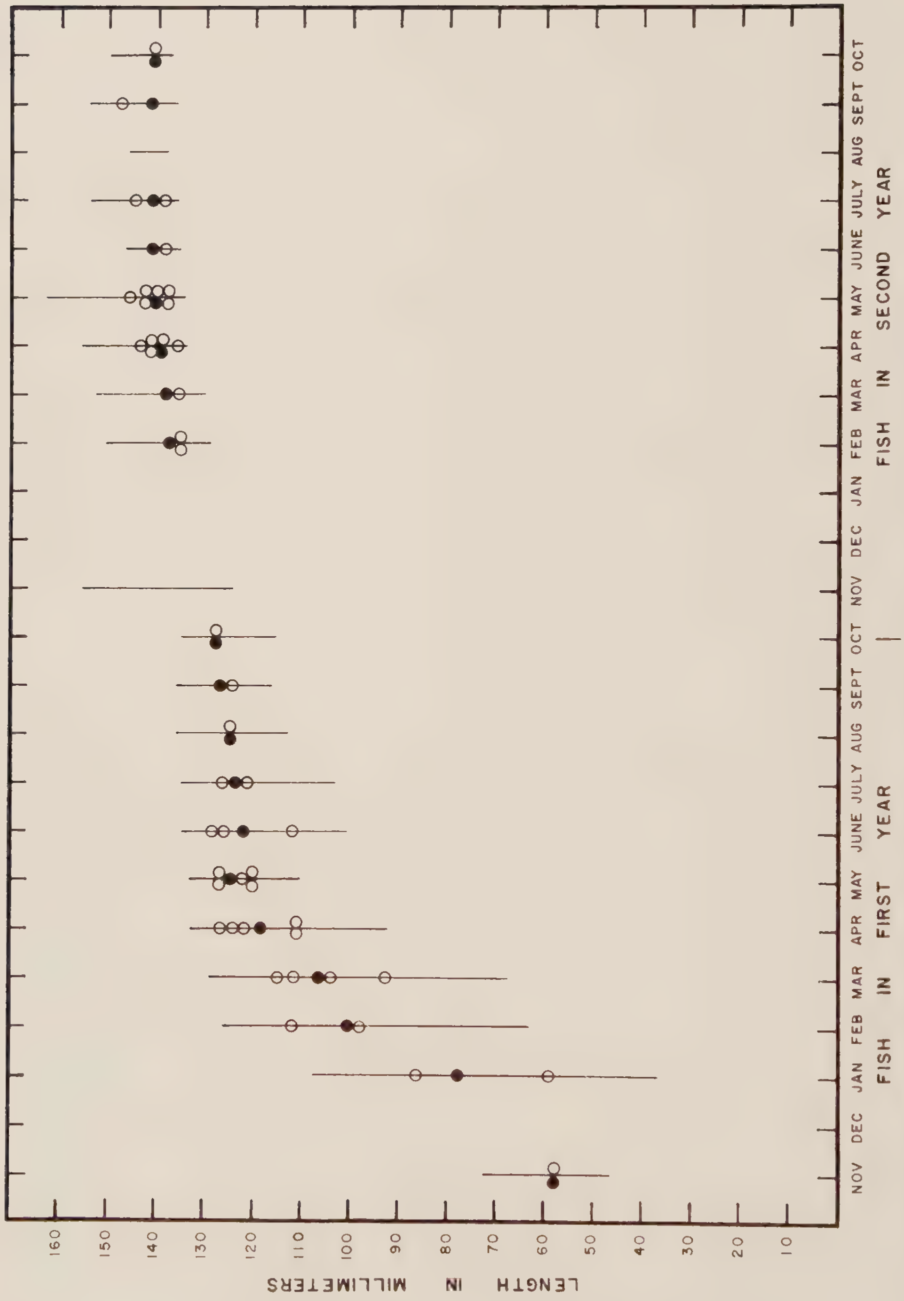


Figure 20. Mean monthly lengths of anchovetas collected at Guaymas, plotted to depict growth.

Figura 20. Longitudes medias mensuales de las anchovetas recolectadas en Guaymas, graficadas para indicar el crecimiento.

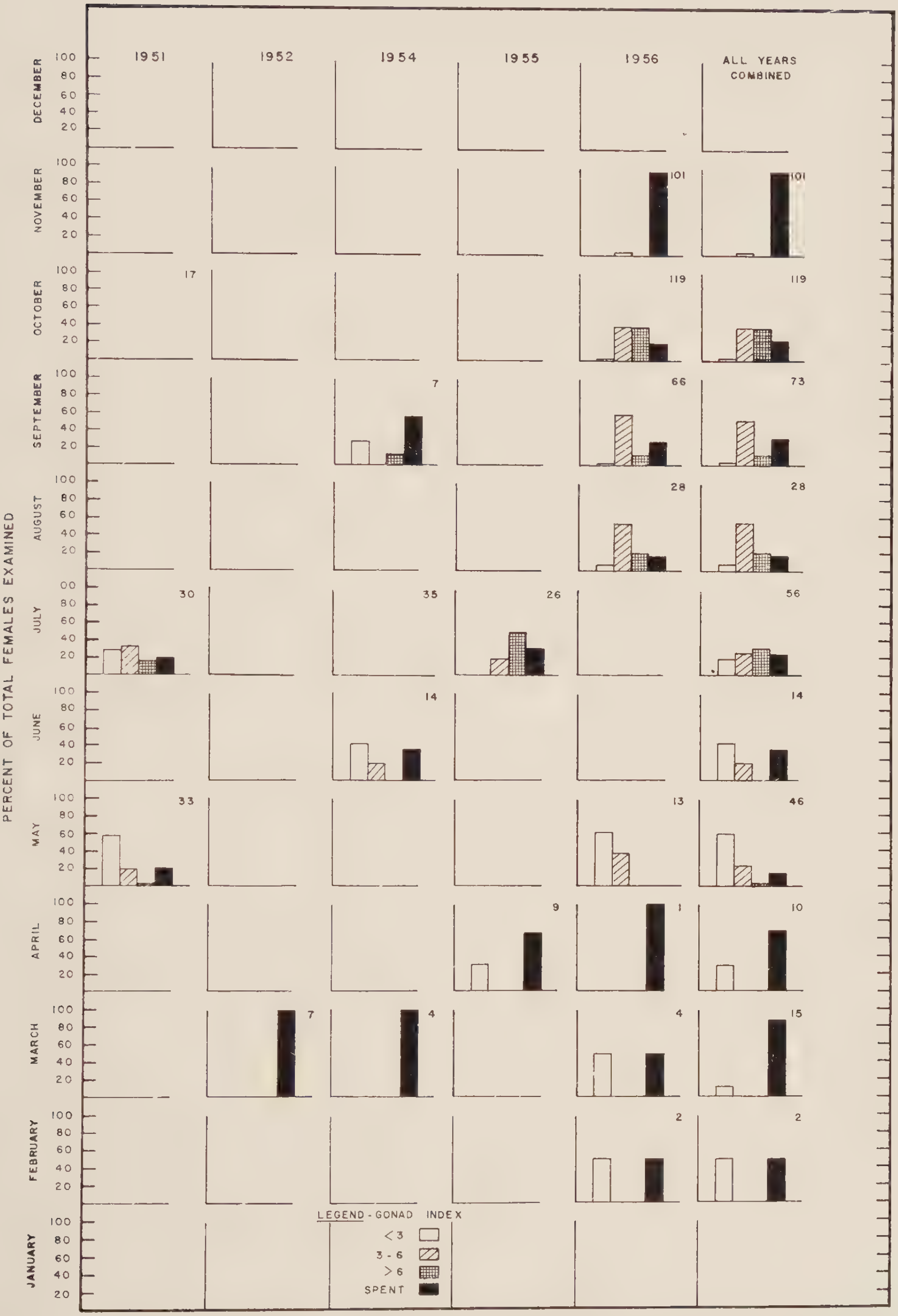


Figure 21. Condition of the ovaries of anchovetas collected at Guaymas from May 1951 through November 1956, and for all years combined, as measured by the gonad index. Monthly distributions are given in per cent. Numbers in panels indicate number of females examined.

Figura 21. Condición de los ovarios de las anchovetas recolectadas en Guaymas de mayo de 1951 a noviembre de 1956 y para todos los años combinados, según la medida del índice de gónadas. Las distribuciones mensuales se dan en porcentajes. Los números en cada panel indican el número de hembras examinadas.

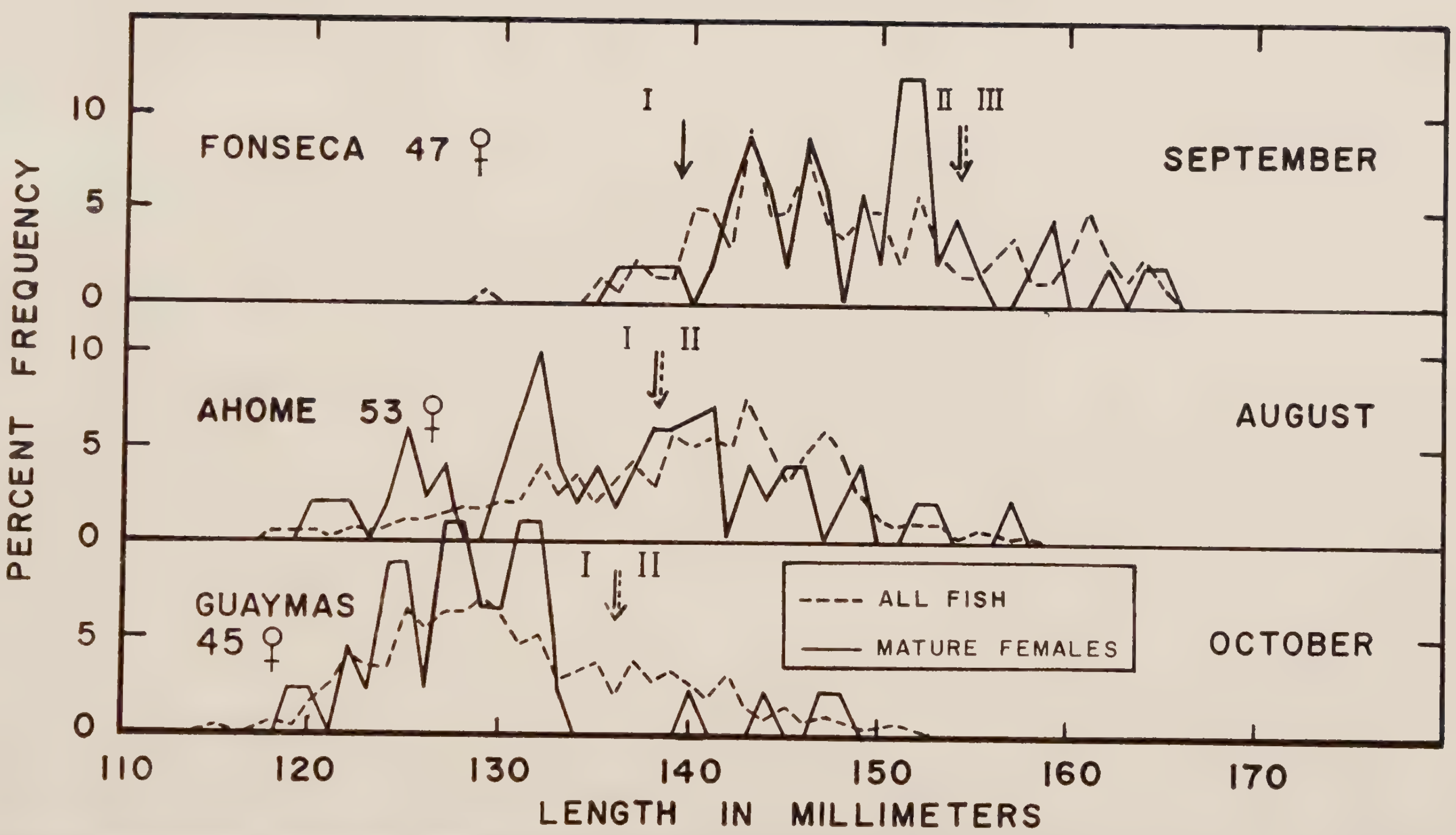


Figure 22. Length-frequency distributions of all mature females and of all anchovetas collected at the Gulf of Fonseca, Ahome Point and Guaymas in September, August and October, respectively.

Figura 22. Distribución de la frecuencia de las longitudes de todas las anchovetas hembras maduras y de todas las anchovetas recolectadas en el Golfo de Fonseca, en Punta Ahome y en Guaymas en septiembre, agosto y octubre, respectivamente.

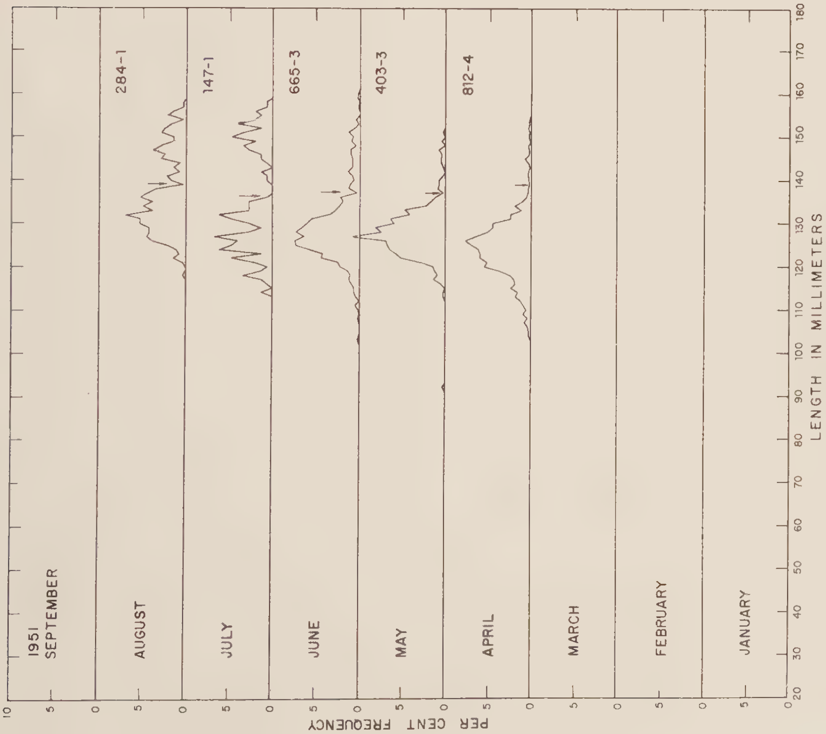


Figure 23. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1951.

Figura 23. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1951.

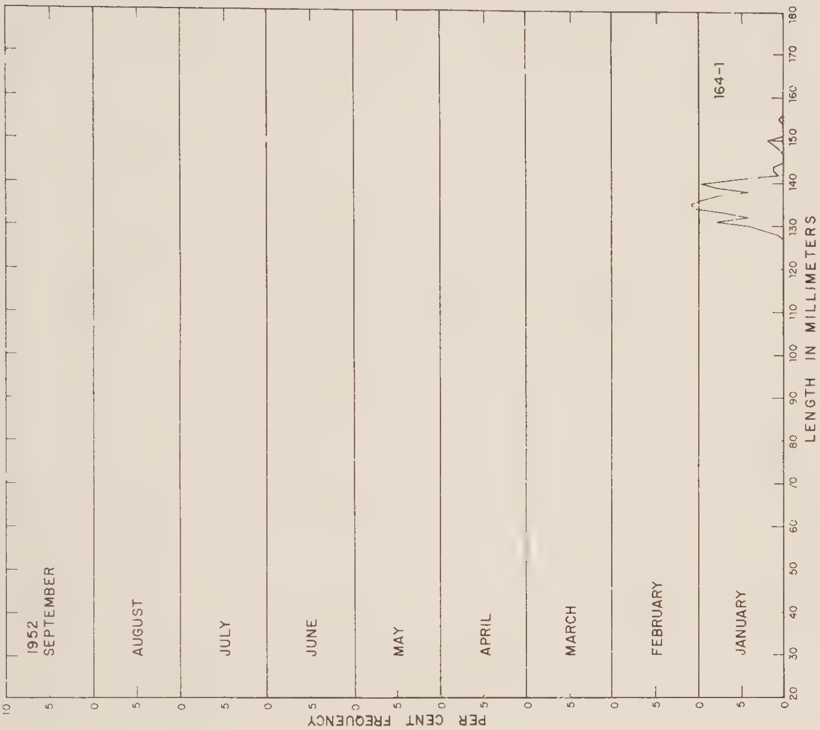


Figure 24. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1952.

Figura 24. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1952.

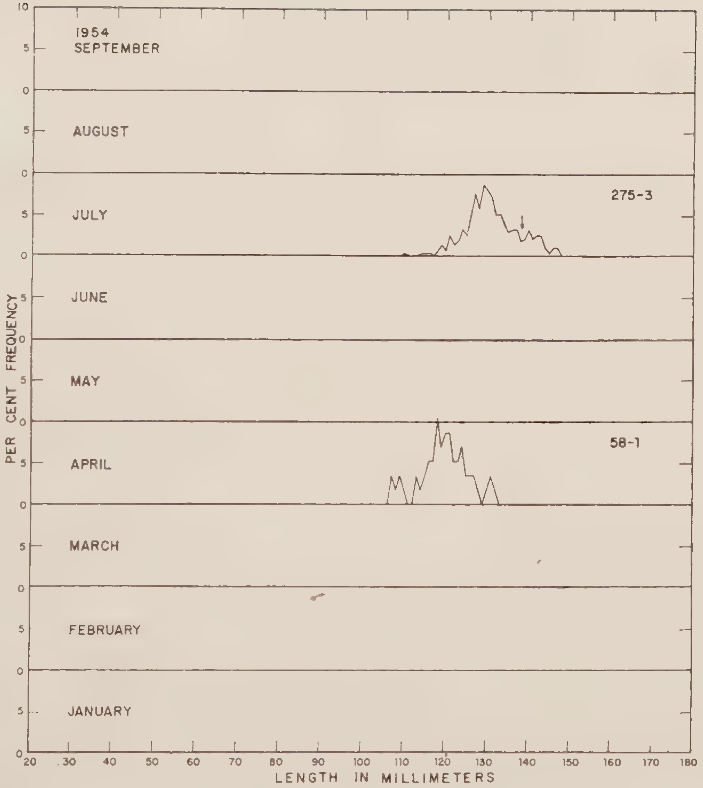


Figure 25. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1954.

Figura 25. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1954.

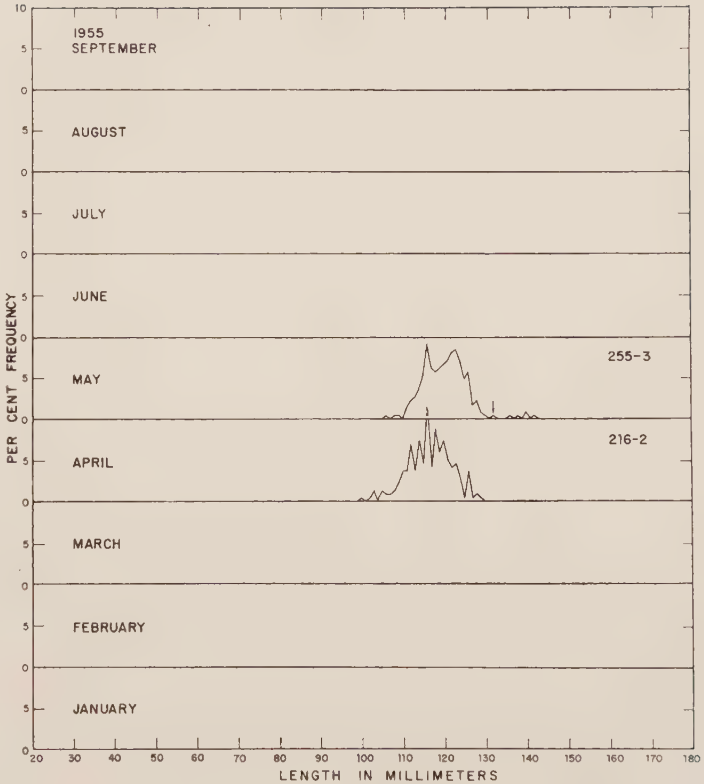


Figure 26. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1955.

Figura 26. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1955.

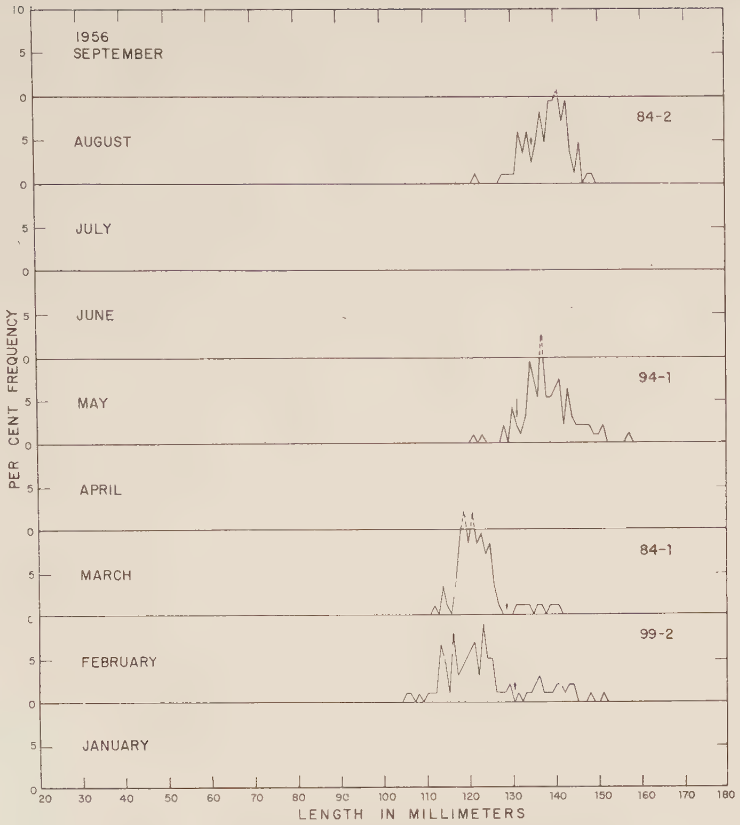


Figure 27. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1956.

Figura 27. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1956.

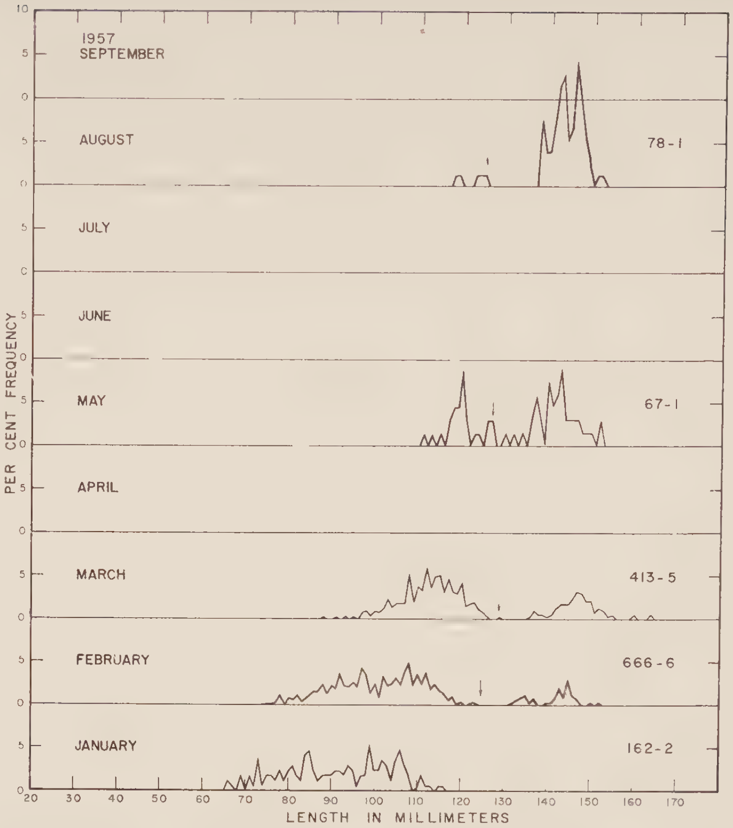


Figure 28. Monthly length-frequency distributions expressed in percentage of anchovetas collected at Ahome Point in 1957.

Figura 28. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en Punta Ahome en 1957.

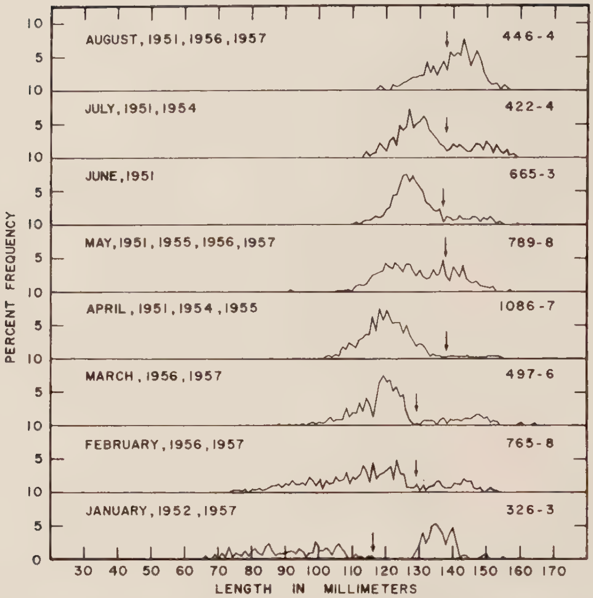


Figure 29. Monthly length-frequency distributions, expressed in percentage, combining all collections of anchovetas made at Ahome Point from 1951 through 1957.

Figura 29. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones de anchovetas hechas en Punta Ahome de 1951 a 1957.

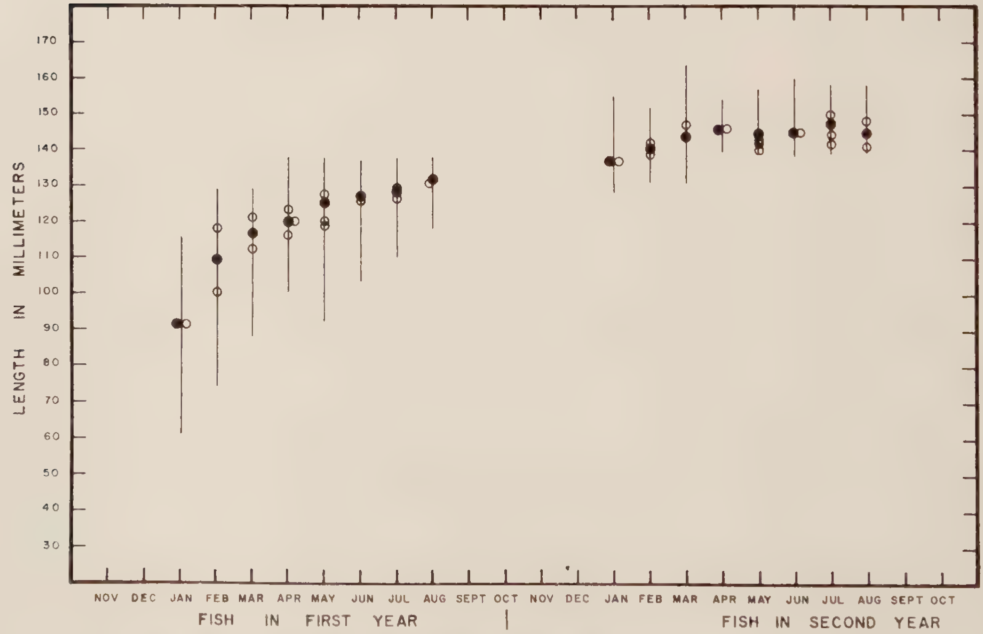
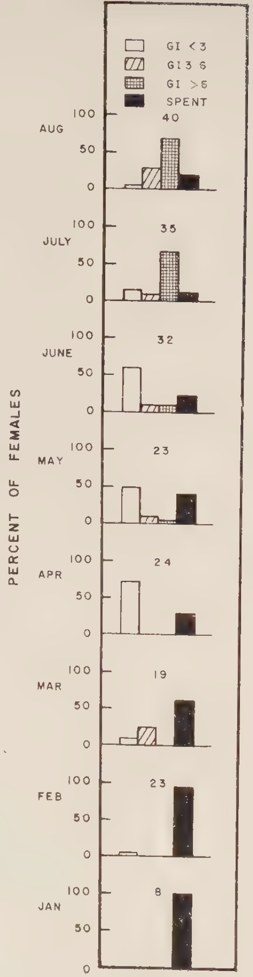


Figure 30. Mean monthly lengths of anchovetas collected at Ahome Point, plotted to depict growth.

Figura 30. Longitudes medias mensuales de las anchovetas recolectadas en Punta Ahome, graficadas para indicar el crecimiento.



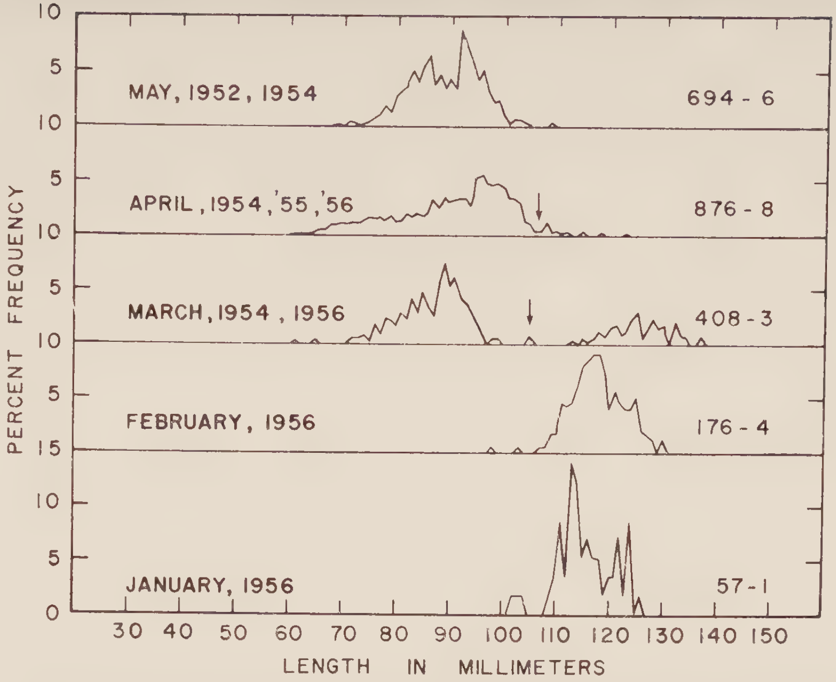


Figure 32. Monthly length-frequency distributions, expressed in percentage, combining all collections of anchovetas made at Banderas Bay from May 1952 through April 1956.

Figura 32. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones de anchovetas hechas en la Bahía Banderas de mayo de 1952 a abril de 1956.

Figure 31. Condition of the ovaries of anchovetas as measured by the gonad index, combining all collections made at Ahome Point from April 1951 through August 1957. Monthly distributions are given in percent. Numbers in panels indicate number of females examined.

Figura 31. Condición de los ovarios de las anchovetas según la medida del índice de gónadas, combinando todas las recolecciones hechas en Punta Ahome de abril de 1951 a agosto de 1957. Las distribuciones mensuales se dan en porcentajes. Los números en cada panel indican el número de hembras examinadas.

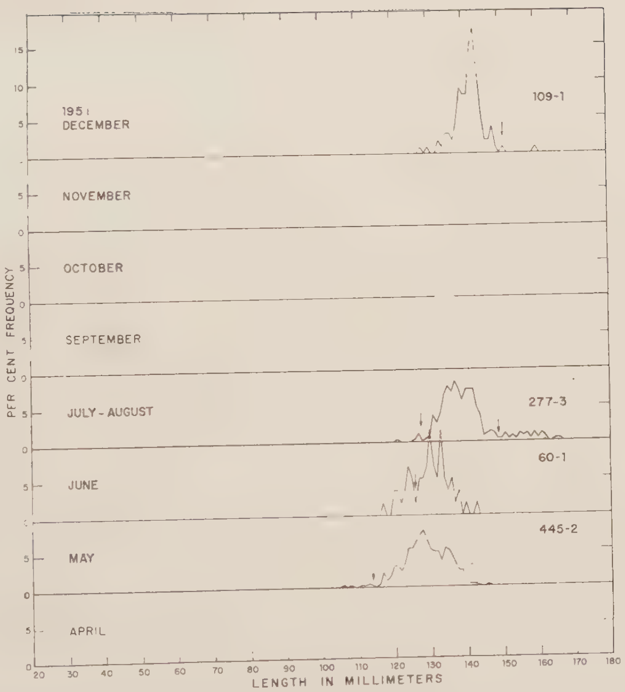


Figure 33. Monthly length-frequency distributions expressed in percentage of anchovetas collected at the Gulf of Fonseca in 1951.

Figura 33. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en el Golfo de Fonseca en 1951.

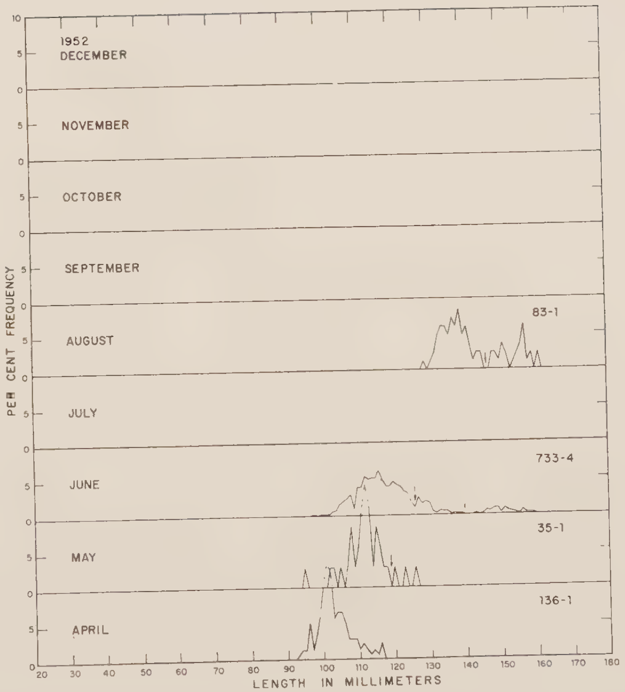


Figure 34. Monthly length-frequency distributions expressed in percentage of anchovetas collected at the Gulf of Fonseca in 1952.

Figura 34. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas recolectadas en el Golfo de Fonseca en 1952.

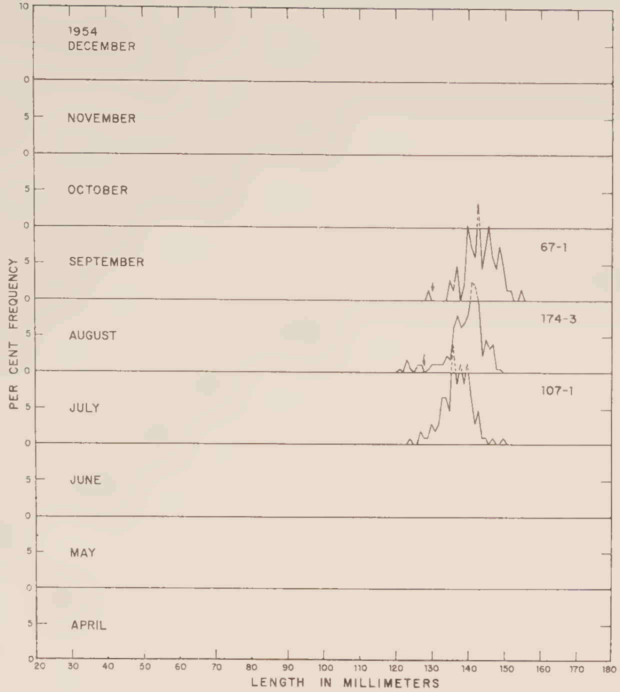


Figure 35. Monthly length-frequency distributions expressed in percentage of anchovetas collected at the Gulf of Fonseca in 1954.

Figura 35. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas reçolectadas en el Golfo de Fonseca en 1954.

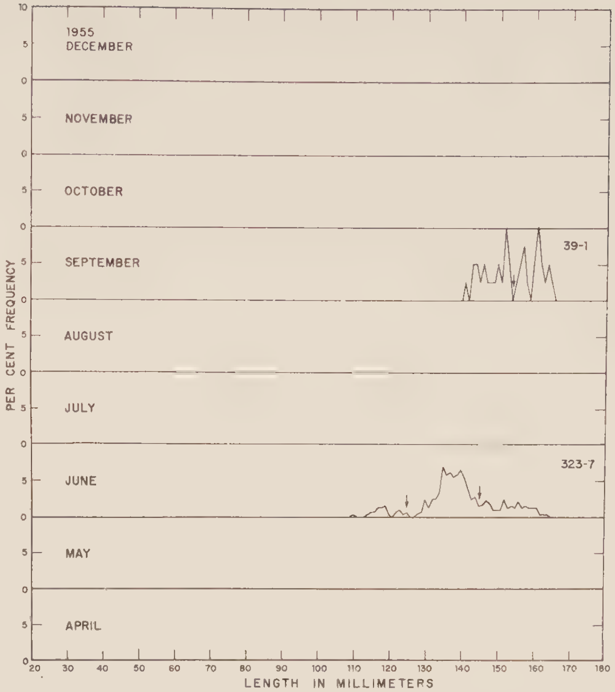


Figure 36. Monthly length-frequency distributions expressed in percentage of anchovetas collected at the Gulf of Fonseca in 1955.

Figura 36. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes de las anchovetas reçolectadas en el Golfo de Fonseca en 1955.

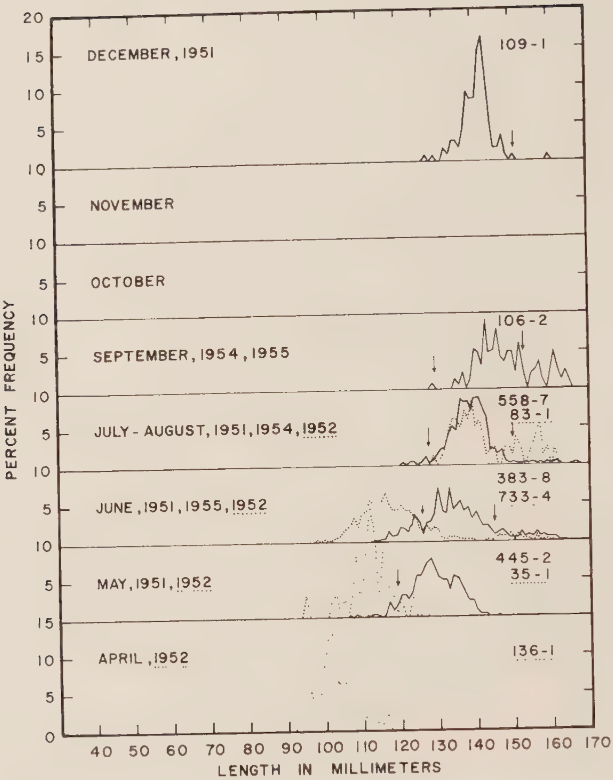


Figure 37. Monthly length-frequency distributions, expressed in percentage, combining all collections made at the Gulf of Fonseca from May 1951 through September 1955. The broken lines represent collections made in 1952.

Figura 37. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones hechas en el Golfo de Fonseca de mayo de 1951 a septiembre de 1955. Las líneas de puntos representan las recolecciones hechas en 1952.

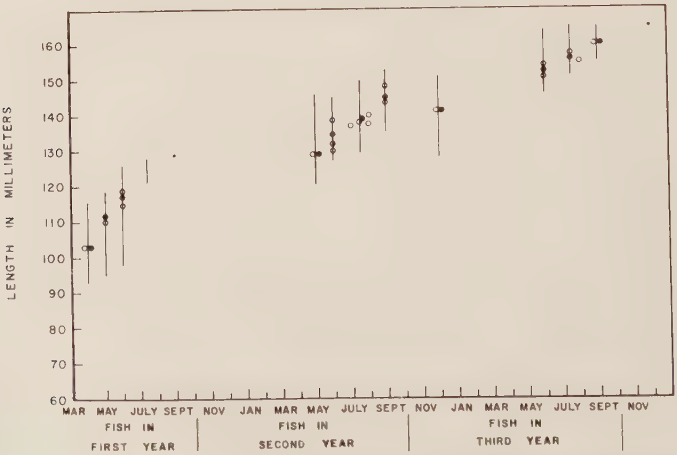


Figure 38. Mean monthly lengths of anchovetas collected at the Gulf of Fonseca, plotted to depict growth.

Figura 38. Longitudes medias mensuales de las anchovetas recolectadas en el Golfo de Fonseca, graficadas para indicar el crecimiento.

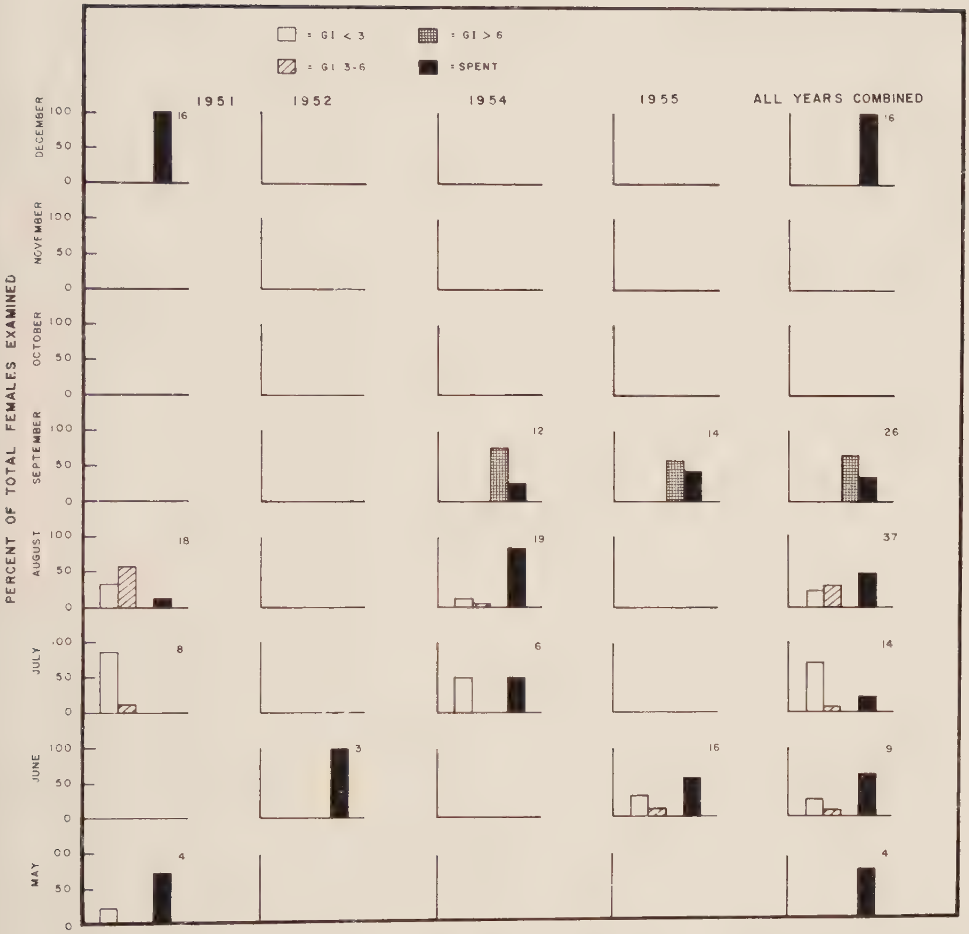


Figure 39. Condition of the ovaries of anchovetas collected at the Gulf of Fonseca from May 1951 through September 1955, and for all years combined, as measured by the gonad index. Monthly distributions are given in per cent. Numbers in panels indicate number of females examined.

Figura 39. Condición de los ovarios de las anchovetas recolectadas en el Golfo de Fonseca de mayo de 1951 a septiembre de 1955, y para todos los años combinados, según la medida del índice de gónadas. Las distribuciones mensuales se dan en porcentajes. Los números en cada panel indican el número de hembras examinadas.

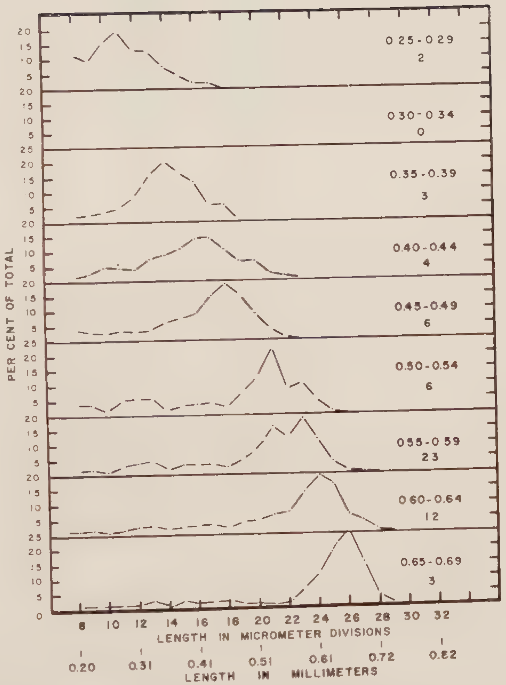


Figure 40. Representation of the course of development of ovarian eggs above 0.20 mm. from anchovetas collected at the Gulf of Fonseca, by grouping length-frequency distributions of ovarian eggs according to the position of the mode of largest eggs. Lower number in panels indicates number of females.

Figura 40. Representación del curso del desarrollo de los huevos ováricos de más de 0.20 mm., de anchovetas recolectadas en el Golfo de Fonseca, agrupando las distribuciones de la frecuencia de las longitudes de los huevos ováricos de acuerdo con la posición del grupo modal de los huevos de mayor tamaño. Los números de abajo en los paneles indican el número de hembras.

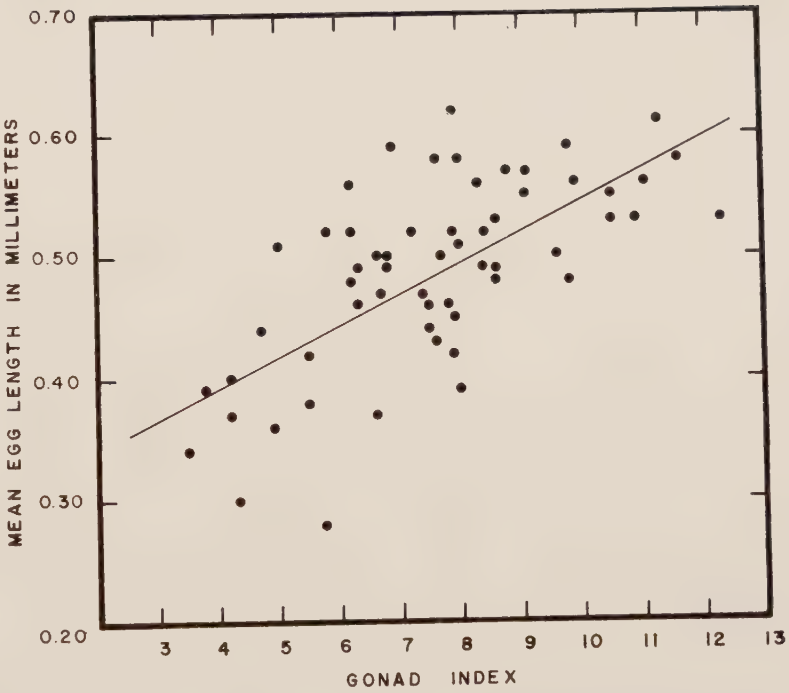


Figure 41. Relationship between value of gonad index and mean length of eggs ≧0.20 mm., for anchovetas collected at the Gulf of Fonseca.

Figura 41. Relación entre el valor del índice de gónadas y la longitud media de los huevas ≧ 0.20 mm., para las anchovetas recolectadas en el Golfo de Fonseca.

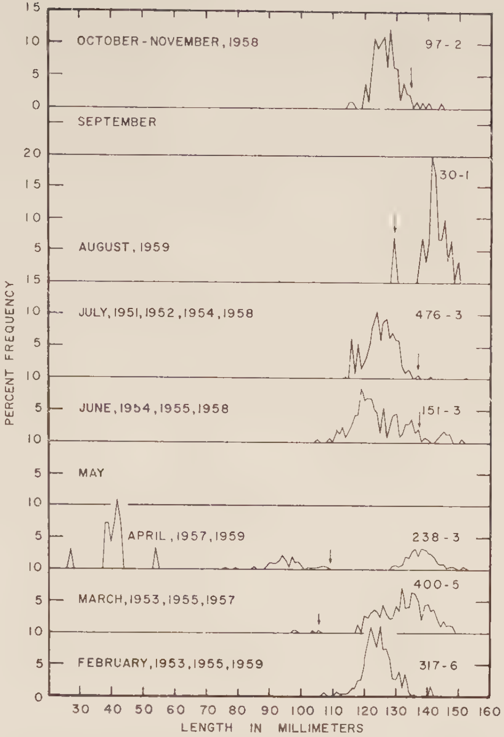


Figure 42. Monthly length-frequency distributions, expressed in percentage, combining all collections made along the coast of Colombia from July 1951 through August 1959.

Figura 42. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones hechas a lo largo de la costa de Colombia de julio de 1951 a agosto de 1959.

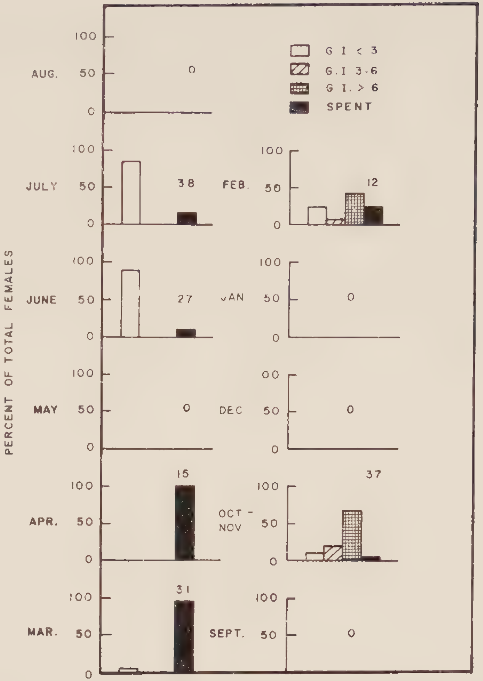


Figure 43. Condition of the ovaries of anchovetas as measured by the gonad index, combining all collections made along the coast of Colombia from July 1951 through February 1959. Monthly distributions are given in per cent. Numbers in panels indicate number of females examined.

Figura 43. Condición de los ovarios de las anchovetas según la medida del índice de gónadas combinando todas las recolecciones hechas a lo largo de la costa de Colombia de julio de 1951 a febrero de 1959. Las distribuciones mensuales se dan en porcentajes. Los números en los paneles indican el número de hembras examinadas.

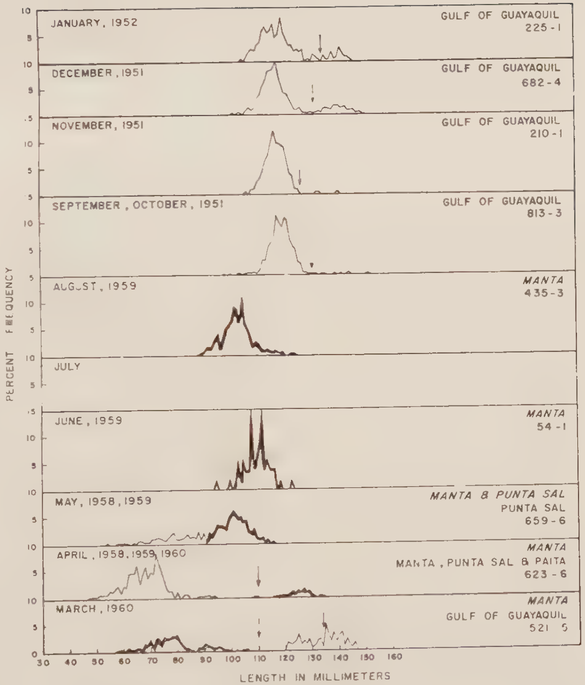


Figure 44. Monthly length-frequency distributions, expressed in percentage, combining all collections made along the coast of Ecuador-Peru from September 1951 through August 1959.

Figura 44. Distribuciones mensuales de la frecuencia de las longitudes expresadas en porcentajes combinando todas las recolecciones hechas a lo largo de las costas de Ecuador-Perú de septiembre de 1951 a agosto de 1959.

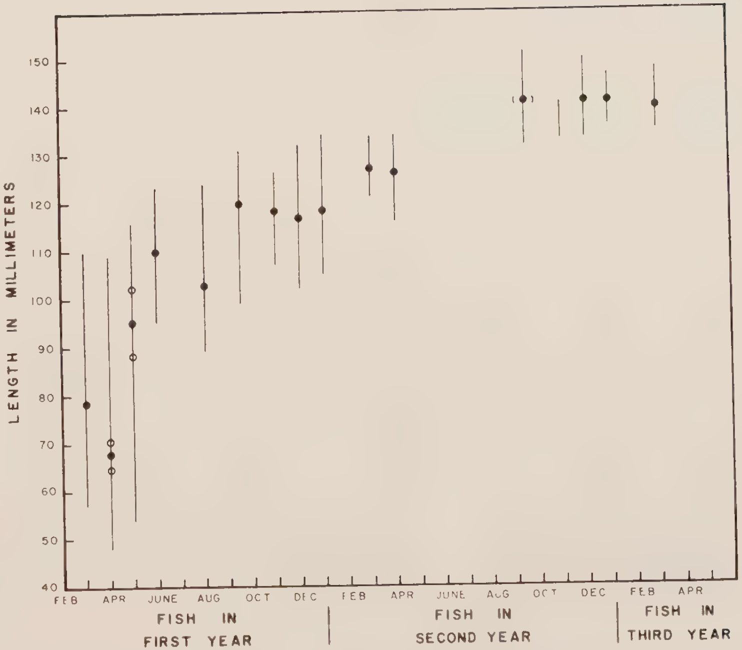


Figure 45. Mean monthly lengths of anchovetas collected along the coast of Ecuador-Peru, plotted to depict growth.

Figura 45. Longitudes medias mensuales de las anchovetas recolectadas a lo largo de las costas de Ecuador-Perú, graficadas para indicar el crecimiento.

TABLE 1. Number of collections and number of anchovetas measured for age and growth, and the years collections were made; for all baiting areas.

TABLA 1. Número de recolecciones y número de anchovetas medidas para determinar la edad y el crecimiento, incluyendo los años en que las recolecciones fueron hechas; para todas las áreas de carnada.

Area Area	Years collected Recolecciones en los años:	Number of collections Número de recolecciones	Number of specimens Número de especímenes
Almejas Bay	1951-1959	109	14,097
Guaymas	1951-1957	69	8,887
Ahome Point	1951-1957	43	4,996
Banderas Bay	1952-1956	22	2,211
Gulf of Fonseca	1951-1955	27	2,588
Colombia	1951-1959	25	1,709
Ecuador-Peru	1951-1960	31	4,238
		326	38,726

TABLE 2. Number of collections and number of anchovetas measured for age and growth according to month and year; from Almejas Bay, 1951-1959.

TABLA 2. Número de recolecciones y número de anchovetas de la Bahía de Almejas, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1959.

Month	1951		1952		1953		1954		1955		1956		1957		1958		1959		Total	
	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.
Mes	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.	Número de: Rec.	Espec.
Jan.			2	154	11	2284			4	301	2	129	1	13	4	449	1	106	25	3436
Feb.			1	229	6	1064			2	311	2	122			2	122	1	185	14	2033
March					1	245					2	197			3	177	2	164	8	783
April	2	336									1	54			4	235			7	625
May	2	207													3	540			5	747
Aug.											1	186			2	116			3	302
Sept.	2	175	2	67			1	78	2	401	3	134	3	448					13	1303
Oct.	1	116	1	351			1	301					3	358					6	1126
Nov.	1	175	1	234	1	135			4	305			3	368					10	1217
Dec.			4	1322	1	141	1	103	8	734	1	24	2	179	1	22			18	2525
	8	1009	11	2357	20	3869	3	482	20	2052	12	846	12	1366	19	1661	4	455	109	14097

TABLE 3. Collections of anchovetas from Almejas Bay, 1951-1959, examined for sexual maturity, showing numbers examined, sex ratio and degree of maturity of the females as indicated by the gonad index; by months collected and combined for all years.

TABLA 3. Recolecciones de anchovetas de la Bahía de Almejas, de 1951-1959, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Year	Month	No. examined for sexual maturity	SEX			GONAD INDEX						Spent females	
			Male	Female	Unident.	<3 No.	%	3-6 No.	%	>6 No.	%	No.	%
Recolectadas en: Año	Mes	Nos. examinados para la madurez sexual	SEXO			INDICE DE GONADAS						Hembras desovadas	
			Macho	Hembra	No ident.	<3 No.	%	3-6 No.	%	>6 No.	%	No.	%
1951	April	15	4	11	0							11	100
	Sept.	22	14	8	0							8	100
	Oct.	21	9	12	0							12	100
	Nov.	33	8	17	8	2	12					15	88
1952	Jan.	35	14	21	0			7	33	8	38	6	29
	Feb	15	0	15	0			2	13	13	87		
	Nov.	10	2	5	3	3	60					2	40
	Dec.	10	0	2	8	2	100						
1953	Jan.	51	13	20	18	12	60					8	40
	Feb.	10	0	7	3	7	100						
	March	10	0	10	0								
	Dec.	17	0	10	7	10	100						
1954	Oct.	11	0	1	10	1	100						
1955	Jan.	54	6	21	27	20	95					1	5
	Feb.	26	8	13	5	4	31					9	69
	Dec.	62	3	18	41	18	100						
1956	Feb.	50	28	20	2	5	25					15	75
	March	59	33	22	4	4	18					18	82
	Dec.	23	14	9	0	1	11	5	56	3	33		
1957	Nov.	15	5	8	2	8	100						
1958	Feb.	17	5	10	2	6	60					4	40
	March	19	8	9	2	7	78	2	22				
	April	83	22	49	12	29	59	5	10			15	31
	May	36	12	19	5	7	37	1	5			11	58
	Aug.	38	19	18	1					2	11	16	89
	Dec.	22	13	9	0			3	33	6	67		
1959	Jan.	25	13	12	0							12	100
	Feb.	20	0	2	18							2	100
	March	25	12	13	0							13	100
All years combined:													
	Jan.	165	46	74	45	32	43	7	9	8	11	27	37
	Feb.	138	41	67	30	22	33	2	3	13	19	30	45
	March	113	53	54	6	11	20	2	4			41	76
	April	98	26	60	12	29	49	5	8			26	43
	May	36	12	19	5	7	37	1	5			11	58
	Aug.	38	19	18	1					2	11	16	89
	Sept.	22	14	8	0							8	100
	Oct.	32	9	13	10	1	8					12	92
	Nov.	58	15	30	13	13	43					17	57
	Dec.	134	30	18	56	31	64	8	17	9	19		

TABLE 4. Number of collections and number of anchovetas measured for age and growth according to month and year; from Guaymas, 1951-1957.

TABLA 4. Número de recolecciones y número de anchovetas de Guaymas, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1957.

Month	1951		1952		1953		1954		1955		1956		1957		Total	
	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.
Mes	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.
Jan.							1	217	2	414					3	631
Feb.			2	530							6	596			8	1126
March			2	560			4	521			2	163	1	197	9	1441
April	2	228	2	357					1	103	3	191	3	349	11	1228
May	6	917	2	260	2	218			2	151	2	127	1	62	15	1735
June			2	367	1	29	3	178							6	574
July	3	289							3	363					6	652
Aug.											1	212			1	212
Sept.							1	163			4	441			5	604
Oct.											3	362			3	362
Nov.											2	322			2	322
	11	1434	10	2074	3	247	9	1079	8	1031	23	2414	5	608	69	8887

TABLE 5. Number of anchovetas collected each month at Guaymas, 1951-1958, according to age, giving size range and mean length. In the last column on the right the data for all years are combined.

TABLA 5. Número de anchovetas recolectadas cada mes en Guaymas, de 1951 a 1958, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados se dan en la última columna de la derecha.

	1951			1952			1953			1954		
	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.
	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.
Fish in first year collected in Nov.												
Jan.										217	63-108	87.25
Feb.				495	63-111	98.34						
March				146	95-117	104.76				499	67-125	93.48
April	132	115-133	125.13	331	97-125	111.39						
May	500	107-132	125.78	209	112-132	121.38	191	110-134	123.15			
June				365	100-124	112.44	29	118-134	128.34	108	108-134	127.10
July	141	115-132	125.86									
Aug.												
Sept.										163	116-143	126.50
Oct.												
Fish in second year collected in Nov.												
Feb.				35	125-151	136.21						
March				414	126-151	138.45				22	127-154	137.90
April	96	134-156	141.09	26	128-148	136.50						
May	417	133-154	139.54	51	135-163	145.67	27	137-153	142.56			
June				2	130-139	——				70	135-147	139.20
July	148	133-154	138.79									
Aug.												
Sept.												
Oct.												
Total	1434			2074			247			1079		

Table 5, No. 2 (Guaymas)

	1955			1956			1957			All years combined		
	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.
	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.
Fish in first year collected in Nov.				100	46-73	57.80				100	46-73	57.80
Jan.	414	36-87	59.14							631	36-108	78.33
Feb.				585	94-126	111.92				1080	63-126	100.50
March				154	93-131	115.04	197	95-126	111.68	998	67-129	106.46
April	89	107-133	124.39	82	112-132	123.04	333	92-128	111.38	973	92-133	117.94
May	122	116-133	125.40	55	116-131	126.29	48	110-132	122.50	1158	110-133	123.94
June										522	100-135	122.28
July	324	102-138	123.80							485	102-135	124.35
Aug.				205	113-136	124.83				205	113-136	124.83
Sept.				323	116-136	127.44				477	116-136	126.97
Oct.				276	115-136	127.92				276	115-136	127.92
Fish in second year collected in Nov.				222	124-156	——				222	124-156	——
Feb.				11	133-146	136.74				46	129-151	136.99
March				9	133-150	(136.55)				443	130-154	138.46
April	14	135-148	141.51	109	134-151	140.00	16	136-151	143.50	255	134-156	140.60
May	29	134-147	140.86	72	132-151	138.96	14	137-152	142.79	577	134-163	141.16
June										52	135-147	140.00
July	39	139-151	144.94							167	136-154	141.16
Aug.				7	138-146	——				7	138-146	---
Sept.				118	137-155	147.63				127	137-155	141.26
Oct.				86	137-151	140.90				86	137-151	140.90
Total	1031			2414			608			8887		

TABLE 6. Number and percentage of anchovetas in their first, second and third years, by areas for all years combined.

TABLA 6. Número y porcentaje de anchovetas en su primer, segundo y tercer año, por áreas y para todos los años combinados.

Area	Total number of specimens	Year I		Year II		Year III	
		Number	Percent	Number	Percent	Number	Percent
Area	Numero total de especímenes	Año I		Año II		Año III	
		Número	Porcentaje	Número	Porcentaje	Número	Porcentaje
Guaymas	8,887	6,905	77.7	1,982	22.3		
Ahome	4,996	4,068	81.4	928	18.6		
Banderas	2,211	1,853	83.8	358	16.2		
Fonseca	2,588	868	33.5	1,410	54.5	310	12.0
Colombia	1,709	708	41.4	1,001	58.6		
Ecuador-Peru	4,238	3,820	90.1	331	7.8	87	2.1

TABLE 7. Collections of anchovetas from Guaymas, 1951-1956, examined for sexual maturity, showing numbers examined, sex ratio and degree of maturity of the females as indicated by the gonad index; by months collected and combined for all years.

TABLA 7. Recolecciones de anchovetas de Guaymas, de 1951-1956, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Year	Collected in: Month	No. examined for sexual maturity	SEX			GONAD INDEX						Spent females	
			Male	Female	Unident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
Recolectadas en: Año	Recolectadas en: Mes	Nos. examinados para la madurez sexual	SEXO			INDICE DE GONADAS						Hembras desovadas	
			Macho	Hembra	No ident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
1951	May	66	16	33	17	19	58	6	19	1	3	7	21
	July	61	19	30	12	9	30	10	33	5	17	6	20
1952	March	10	3	7	0							7	100
1954	March	9	3	4	2							4	100
	June	17	3	14	0	6	43	3	21			5	36
	July												
	Sept.	22	6	7	9	2	29			1	14	4	57
1955	April	29	2	9	18	3	33					6	67
	May	10	0	0	10								
	July	47	19	26	2			5	19	13	50	8	31
1956	Feb.	20	0	2	18	1	50					1	50
	March	15	1	4	10	2	50					2	50
	April	7	2	1	4							1	100
	May	42	12	13	17	8	62	5	38				
	Aug.	37	9	28	0	2	7	15	54	6	21	5	18
	Sept.	100	33	66	1	1	1	38	58	8	12	19	29
	Oct.	199	79	119	1	2	2	47	39	46	39	24	20
	Nov.	101	49	51	1			2	4			49	96
All years combined:													
	Feb.	20	0	2	18	1	50					1	50
	March	34	7	15	12	2	13					13	87
	April	37	4	10	22	3	30					7	70
	May	118	28	46	44	27	59	11	24	1	2	7	15
	June	17	3	14	0	6	43	3	21			5	36
	July	108	38	56	14	9	16	15	27	18	32	14	25
	Aug.	37	9	28	0	2	7	15	54	6	21	5	18
	Sept.	122	39	73	10	3	4	38	52	9	12	23	32
	Oct.	199	79	119	1	2	2	47	39	46	39	24	20
	Nov.	101	49	51	1			2	4			49	96

TABLE 8. Number of collections and number of anchovetas measured for age and growth according to month and year; from Ahome Point, 1951-1957.

TABLA 8. Número de recolecciones y número de anchovetas de Punta Ahome, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1957.

Year Año	Month Mes	Number of collections Número de recolecciones	Number of specimens Número de especímenes
1951	April	4	812
	May	3	403
	June	3	665
	July	1	147
	Aug.	1	284
1952	Jan.	1	164
1954	April	1	58
	July	3	275
1955	April	2	216
	May	3	225
1956	Feb.	2	99
	March	1	84
	May	1	94
	Aug.	2	84
1957	Jan.	2	162
	Feb.	6	666
	March	5	413
	May	1	67
	Aug.	1	78
	Total	43	4996

TABLE 9. Number of anchovetas collected each month at Ahome Point, 1951-1957, according to age, giving the size range and mean length. In the last column on the right the data for all years are combined.

TABLA 9. Número de anchovetas recolectadas cada mes en Punta Ahome, de 1951 a 1957, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados se dan en la última columna de la derecha.

		1951			1952			1954			1955			1956			1957			All years combined	
		No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.
		No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.
Fish in first year collected in:	Jan.																162	66-116	91.43	162	66-116	91.43
	Feb.													77	105-129	118.58	579	74-125	100.57	656	74-129	109.31
	March													75	112-127	120.88	304	88-129	112.47	379	88-129	117.08
	April	780	104-138	123.52				58	107-132	119.75	216	100-129	116.46							1054	100-138	119.64
	May	378	92-137	127.04							220	105-131	118.97	11	121-132	——	25	111-127	119.96	692	92-138	125.67
	June	570	103-137	126.53																570	103-137	126.53
	July	96	114-136	126.51				230	110-138	129.08										326	110-138	127.95
	Aug.	190	118-139	131.24										20	122-135	——	5	118-125	——	229	118-138	131.72
Fish in second year collected in:	Jan.				164	128-155	136.81													164	128-155	136.81
	Feb.													22	131-151	139.41	87	132-152	141.69	109	131-152	139.99
	March													9	131-141	——	109	136-164	146.97	118	131-164	143.77
	April	32	139-154	145.62																32	139-154	145.62
	May	25	138-151	143.21							5	136-142	——	83	133-157	139.64	42	130-152	141.81	97	139-157	143.73
	June	95	138-160	145.54																95	138-160	145.54
	July	51	140-158	149.96				45	139-147	142.02										96	139-158	147.41
	Aug.	94	140-158	148.18										64	136-149	140.78	73	138-152	143.77	217	139-158	144.44
Total		2311			164			333			441			361			1386			4996		

TABLE 10. Collections of anchovetas from Ahome Point, 1951-1957, examined for sexual maturity, showing numbers examined, sex ratio and degree of maturity of the females as indicated by the gonad index; by months collected and combined for all years.

TABLA 10. Recolecciones de anchovetas de Punta Ahome, de 1951-1957, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Year	Month	No. examined for sexual maturity	SEX			GONAD INDEX						Spent females	
			Male	Female	Unident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
Recolectadas en: Año	Mes	Nos. examinados para la madurez sexual	SEXO			INDICE DE GONADAS						Hembras desovadas	
			Macho	Hembra	No ident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
1951	April	54	1	14	39	10						4	
	May	20	0	5	15	5							
	June	75	11	32	32	19		3		3		7	
	July	32	8	24	0	1		1		18		4	
	Aug.	25	9	16	0	1		2		12		1	
1952	Jan.	14	6	8	0							8	
1954	May	10	0	0	10								
	July	28	16	11	1	4		2		5			
1955	April	10	0	0	10								
1956	Feb.	20	6	3	11							3	
	March	16	0	4	12	2						2	
	May	31	7	18	6	6		2		1		9	
	Aug.	53	34	19	0			2		15		2	
1957	Feb.	31	7	20	3	1						19	
	March	28	8	15	5			5				10	
	Aug.	14	7	5	2							5	
All years combined:													
	Jan.	14	6	8	0							8	100
	Feb.	51	13	23	15	1	4					22	96
	Mar.	44	8	19	17	2	11	5	26			12	63
	April	64	1	14	49	10	71					4	29
	May	61	7	23	31	11	48	2	9	1	4	9	39
	June	75	11	32	32	19	60	3	9	3	9	7	22
	July	60	24	35	1	5	14	3	9	23	66	4	11
	Aug.	92	50	40	2	1	2	4	10	27	68	8	20

TABLE 11. Number of collections and number of anchovetas measured for age and growth according to month and year; from Banderas Bay, 1952-1956.

TABLA 11. Número de recolecciones y número de anchovetas de la Bahía de Banderas, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1952 a 1956.

Collected: Year Recolectadas en: Año	Month Mes	Number of Collections Número de Recolecciones	Number of Specimens Número de Especímenes
1952	May	2	163
1954	March	1	194
	April	4	517
	May	4	531
1955	April	3	293
1956	Jan.	1	57
	Feb.	4	176
	March	2	214
	April	1	66
	Total	22	2211

TABLE 12. Number of anchovetas collected each month at Banderas Bay, 1952-1956, according to age, giving size range and mean length. In the last column on the right the data for all years are combined.

TABLA 12. Número de anchovetas recolectadas cada mes en la Bahía de Banderas, de 1952 a 1956, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados se dan en la última columna de la derecha.

	1952			1954			1955			1956			All years combined		
	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.
Fish in first year collected in:															
March				192	78-105	89.88				108	61-93	85.14	300	61-105	86.77
April				516	61- 97	80.01	277	78-107	95.27	66	82-108	96.57	859	61-107	90.64
May	163	71-109	91.52	531	69-105	86.81							694	69-109	89.20
Fish in second year collected in:															
Jan.										57	102-126	115.25	57	102-126	115.25
Feb.										176	98-130	117.83	176	98-130	117.83
March				2	120	——				106	113-137	125.58	108	113-137	125.46
April				1	123	——	16	108-118	——				17	108-123	——
Total	163			1242			293			513			2211		

TABLE 13. Number of collections and number of anchovetas measured for age and growth according to month and year; from the Gulf of Fonseca, 1951-1955.

TABLA 13. Número de recolecciones y número de anchovetas del Golfo de Fonseca, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1955.

Month	1951 Number of:		1952 Number of:		1954 Number of:		1955 Number of:		Total Number of:	
	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.
Mes	Número de:		Número de:		Número de:		Número de:		Número de:	
	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.
April			1	136					1	136
May	2	445	1	35					3	480
June	1	60	4	733			7	323	2	1116
July					1	107			1	107
July-Aug.	3	277							3	277
Aug.			1	83	3	174			4	257
Sept.					1	67	1	39	2	106
Dec.	1	109							1	109
Total	7	891	7	987	5	348	8	362	27	2588

TABLE 14. Number of anchovetas collected each month at the Gulf of Fonseca, 1951-1955, according to age, giving size range and mean length. In the last column on the right the data for all years except 1952 are combined.

TABLA 14. Número de anchovetas recolectadas cada mes en el Golfo de Fonseca, de 1951 a 1955, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados excepto 1952 se dan en la última columna de la derecha.

	1951			1952			1954			1955			Total all years except 1952		
	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.
Fish in first year collected in:															
April				136	93-116	102.43									
May	445	106-146	128.63	35	95-126	119.08							445	106-146	128.63
June	60	117-143	129.73	683	98-139	117.02				265	110-149	136.56	328	110-150	132.88
July							107	124-150	137.06						
July-Aug.	249	121-149	137.94										534	121-151	138.20
Aug.				57	129-145	137.58	174	121-149	139.40						
Sept.							67	129-155	143.70	20	141-153	148.04	85	129-153	145.08
Fish in second year collected in:															
Dec.	108	128-151	141.44										108	128-151	141.44
June				50	143-159	150.46				58	150-164	155.86	55	151-164	156.18
July-Aug.	28	150-166	157.00										24	152-166	158.04
Aug.				26	148-161	154.46									
Sept.										19	155-165	160.00	21	155-165	159.85
Fish in third year collected in:															
Dec.	1	160	——										1	160	——
Total	891			987			348			362			1601		

TABLE 15. Collections of anchovetas from the Gulf of Fonseca, 1951-1955, examined for sexual maturity, showing numbers examined, sex ratio and degree of maturity of the females as indicated by the gonad index; by months collected and combined for all years.

TABLA 15. Recolecciones de anchovetas del Golfo de Fonseca, de 1951-1955, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Year	Month	No. examined for sexual maturity	SEX			GONAD INDEX						Spent females	
			Male	Female	Unident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
Recolectadas en: Año	Mes	Nos. examinados para la madurez sexual	SEXO			INDICE DE GONADAS						Hembras desovadas	
			Macho	Hembra	No ident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
1951	May	26	10	4	12	1	25					3	75
	June	15	0	0	15								
	July	25	2	8	15	7	88	1	12				
	Aug.	41	9	18	14	6	33	10	56			2	11
	Dec.	30	14	16	0							16	100
1952	June	17	3	3	11							3	100
1954	July	14	8	6	0	3	50					3	50
	Aug.	45	26	19	0	2	11	1	5			16	84
	Sept.	25	13	12	0					9	75	3	25
1955	June	46	14	16	16	5	31	2	13			9	56
	Sept.	28	14	14	0					8	57	6	43
All years combined:													
	May	26	10	4	12	1	25					3	75
	June	78	17	19	42	5	26	2	11			12	63
	July	39	10	14	15	10	71	1	7			3	22
	Aug.	86	35	37	14	8	22	11	30			18	48
	Sept.	53	27	26	0					17	65	9	35
	Dec.	30	14	16	0							16	100

TABLE 16. Number of collections and number of anchovetas measured for age and growth according to month and year; from Colombia, 1951-1959.

TABLA 16. Número de recolecciones y número de anchovetas de Colombia, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1959.

Month	1951		1952		1953		1954		1955		1957		1958		1959		Total	
	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.	Number of: Coll.	Spec.
Mes	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.	Número de: Rec.	Espc.
Feb.					1	88			4	209					1	20	6	317
March					2	71			1	78	2	251					5	400
April											2	224			1	14	3	238
June							1	58	1	45			1	48			3	151
July	1	106	2	305			1	15					1	50			5	476
Aug.															1	30	1	30
Oct.-Nov.													2	97			2	97
Total	1	106	2	305	3	159	2	73	6	332	4	475	4	195	3	64	25	1709

TABLE 17. Number of anchovetas collected each month at Colombia, 1951-1959, according to age, giving the size range and mean length. In the last column on the right the data for all years are combined.

TABLA 17. Número de anchovetas recolectadas cada mes en Colombia, de 1951 a 1959, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados se dan en la última columna de la derecha.

	1951			1952			1953			1954			1955		
	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.
	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.	No. de espc.	Ampl. tamaño mm.	Long. media mm.
Fish in first year collected in: March															
April "A"															
April "B"															
June										47	105-129	119.96	23	117-131	127.17
July	106	114-141	127.65	304	117-136	127.65				15	116-127	121.13			
Aug.															
Oct.-Nov.															
Fish in second year collected in: Feb.							88	120-136	126.88				209	107-145	124.79
March							71	116-132	124.54				78	126-153	135.74
April															
June										11	137-151	144.27	22	132-147	135.68
July				1	152	—									
Aug.															
Total	106			305			159			73			332		

Table 17, No. 2 (Colombia)

	1957			1958			1959			All years combined		
	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.	No. of spec. No. de espc.	Size range mm. Ampl. tamaño mm.	Mean length mm. Long. media mm.
Fish in first year collected in:												
March	4	98-106	——							4	98-106	——
April "A"	73	76-109	94.92							73	76-109	94.92
April "B"							14	27-54	40.64	14	27-54	40.64
June				48	111-121	119.54				137	105-137	123.28
July				50	116-134	126.66				474	114-137	125.16
Aug.							2	129	——	2	129	——
Oct.-Nov.				93	115-134	125.96				93	115-134	125.96
Fish in second year collected in:												
Feb.							20	121-133	126.25	317	107-145	124.79
March	247	124-148	137.14							396	116-153	132.83
April	151	129-156	138.45							151	129-156	138.45
June										14	139-151	(144.72)
July										2	141-152	——
Aug.							28	137-149	142.36	28	137-149	142.36
Oct.-Nov.				4	136-144	——				4	136-144	——
Total	475			195			64			1709		

TABLE 18. Collections of anchovetas from Colombia, 1951-1959, examined for sexual maturity, showing numbers examined, sex ratio, and degree of maturity of the females as indicated by the gonad index; by month collected and combined for all years.

TABLA 18. Recolecciones de anchovetas de Colombia, de 1951 a 1959, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Recolectadas en:		No. examined for sexual maturity Nos. examinados para la madurez sexual	SEX SEXO			GONAD INDEX INDICE DE GONADAS						Spent females Hembras desovadas	
Year Año	Month Mes		Male Macho	Female Hembra	Unident. No ident.	<3		3-6		>6			
						No.	%	No.	%	No.	%	No.	%
1951	July	28	0	10	18	4						6	
1952	July	29	1	2	26	2							
1953	Feb.	16	0	2	14	2							
	March	16	0	1	15	1							
1954	June	15	4	3	8							3	
	July	15	0	1	14	1							
1955	Feb.	33	8	1	24	1							
1957	March	41	5	30	6							30	
	April	17	2	15	0							15	
1958	June	48	24	24	0	24							
	July	50	25	25	0	25							
	Oct.-Nov.	97	60	37	0	4		7		25		1	
1959	Feb.	20	11	9	0			1		5		3	
All years combined:													
	March	57	5	31	21	1	3					30	97
	April	17	2	15	0							15	100
	June	63	28	27	8	24	89					3	11
	July	122	26	38	58	32	84					6	16
	Oct.-Nov.	97	60	37	0	4	11	7	19	25	67	1	3
	Feb.	69	19	12	38	3	25	1	8	5	42	3	25

TABLE 19. Number of collections and number of anchovetas measured for age and growth according to month and year; from Ecuador-Peru, 1951-1960.

TABLA 19. Número de recolecciones y número de anchovetas de Ecuador-Perú, medidas para determinar la edad y el crecimiento de acuerdo al mes y al año, de 1951 a 1960.

	1951		1952		1958		1959		1960		Total	
Month	Number of:		Number of:		Number of:		Number of:		Number of:		Number of:	
	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.	Coll.	Spec.
Mes	Número de:		Número de:		Número de:		Número de:		Número de:		Número de:	
	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.	Rec.	Espc.
Jan.			1	225					1	16	2	241
March									5	521	5	521
April					1	125	4	381	1	117	6	623
May					3	378	3	281			6	659
June							1	54			1	54
Aug.							3	435			3	435
Sept.-Oct.*	3	813									3	813
Nov.	1	210									1	210
Dec.	4	682									4	682
Total	8	1705	1	225	4	503	11	1151	7	654	31	4238

*Taken Sept. 29 to Oct. 1

*Capturadas de Sept. 29 a Oct. 1o.

TABLE 20. Number of anchovetas collected each month at Ecuador-Peru, 1951-1960, according to age, giving size range and mean length. In the last column on the right the data for all years are combined.

TABLA 20. Número de anchovetas recolectadas cada mes en Ecuador-Perú, de 1951 a 1960, de acuerdo a la edad; se incluye también la amplitud de tamaño y la longitud media. Los datos para todos los años combinados se dan en la última columna de la derecha.

	1951			1952			1958			1959			1960			All years combined		
	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.	No. of spec.	Size range mm.	Mean length mm.
	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.	No. de espec.	Ampl. tamaño mm.	Long. media mm.
Fish in first year collected in: March													364	57-110	78.44	364	57-110	78.44
April							125	52-80	70.51	381	48-93	64.72	5	93-109	——	511	48-109	67.84
May							378	54-114	88.52	281	58-116	102.41				659	54-116	95.47
June										54	95-123	109.81				54	95-123	109.81
Aug.										435	89-124	103.09				435	89-124	103.09
Sept.-Oct.	800	99-131	119.54													800	99-131	119.54
Nov.	207	107-126	117.77													207	107-126	117.77
Dec.	587	102-132	117.03													587	102-132	117.03
Jan.				199	105-134	117.97							4	130-132	——	203	105-134	117.97*
Fish in second year collected in: March													70	121-134	127.10	70	121-134	127.10
April													112	116-134	125.77	112	116-134	125.77
Sept.-Oct.	13	132-152	(140.87)													13	132-152	(140.87)
Nov.	3	133-141	——													3	133-141	——
Dec.	95	133-150	141.10													95	133-150	141.10
Jan.				26	136-146	141.00							12	140-147	——	38	136-147	141.00*
Fish in third year collected in: March													87	135-148	139.49	87	135-148	139.49
Total	1705			225			503			1151			654			4238		

*Does not include 1960 collection. — No incluye las recolecciones de 1960.

TABLE 21. Collections of anchovetas from the Gulf of Guayaquil, 1951-1952, examined for sexual maturity, showing numbers examined, sex ratio and degree of maturity of the females as indicated by the gonad index; by months collected and combined for all years.

TABLA 21. Recolecciones de anchovetas del Golfo de Guayaquil, de 1951 a 1952, examinadas para la madurez sexual, mostrando números examinados, proporción de los sexos y grado de madurez de las hembras según indica el índice de gónadas; por mes y todos los años combinados.

Collected in: Year	Month	No. examined for sexual maturity	SEX			GONAD INDEX						Spent females	
			Male	Female	Unident.	<3 No.	%	3-6 No.	%	>6 No.	%	No.	%
Recolectadas en: Año	Mes	Nos. examinados para la madurez sexual	SEXO			INDICE DE GONADAS						Hembras desovadas	
			Macho	Hembra	No ident.	<3 No.	%	3-6 No.	%	>6 No.	%	No.	%
1951													
	Sept.-Oct.	47	8	12	27	8	66	2	17			2	17
	Nov.	14	0	1	13							1	100
	Dec.	80	22	38	20	5	13	3	8	3	8	27	71
1952	Jan.	28	10	13	5			2	15	4	31	7	54

ESTUDIOS DE LA EDAD, CRECIMIENTO, MADUREZ SEXUAL Y DESOVE DE LAS POBLACIONES DE ANCHOVETA *(CETENGRAULIS MYSTICETUS)* DE LA COSTA DEL OCEANO PACIFICO ORIENTAL TROPICAL

por

Izadore Barrett y Gerald V. Howard[1]

RESUMEN

Trescientas veintiseis recolecciones de anchovetas *(Cetengraulis mysticetus)*, una importante especie de carnada para la pesca del atún, cogidas entre abril de 1951 y abril de 1960 en siete de las mayores áreas de pesca de peces de carnada en el Océano Pacífico Oriental Tropical (Bahía de Almejas, Guaymas, Punta Ahome, Bahía Banderas, Golfo de Fonseca, y las costas de Colombia y de Ecuador-Perú), sirven de base a este estudio de la edad, crecimiento, madurez sexual y desove de dicha especie. El estudio de la progresión temporal de los grupos de tamaños modales según los gráficos de las distribuciones de la frecuencia de las longitudes proporcionó estimaciones de la edad y de la tasa de crecimiento. La investigación de la madurez sexual y la época de desove se basó en el examen macroscópico de los ovarios y en la aplicación del índice de gónadas.

La tabulación que se da a continuación indica las longitudes medias aproximadas a las edades I, II y III y los probables períodos de desove en cada área.

	I	II	III	
Bahía de Almejas	127	146	—	De agosto a febrero
Bahía de Guaymas	128	141	—	De julio a diciembre
Punta Ahome	132	144	—	De junio a septiembre
Bahía Banderas	115	—	—	En algún tiempo entre junio y diciembre
Golfo de Fonseca	128	143	160	De septiembre a diciembre
Golfo de Panamá[1]	126	148	—	De octubre a diciembre
Colombia	126	142	—	De octubre a febrero
Ecuador-Perú	118	141	—	De diciembre a febrero

[1] Tomado de Howard y Landa, 1958

La anchoveta, dentro de su distribución geográfica, tiene una longitud promedio de 115 a 132 mm. al final de su primer año de vida y de 141 a 148 mm. al final de su segundo año. Los peces cuyo tamaño promedio es mayor que éste están en su tercer año o más. La anchoveta de un año constituyó más del 78 por ciento de las poblaciones en todas las áreas, excepto en el Golfo de Fonseca y a lo largo de la costa de Colombia; en

---

[1] Dirección presente: U. S. Bureau of Commercial Fisheries, Biological Laboratory, San Diego, California.

estas últimas áreas, la mayoría de los peces eran de dos años (54 y 59 por ciento, respectivamente). Solamente en el Golfo de Fonseca se encontraron anchovetas de tres años en proporción substancial (12 por ciento).

En todas las áreas el desove ocurre generalmente en los últimos meses del año y puede extenderse a los primeros meses del siguiente. La época de desove puede durar de tres a siete meses en las diferentes áreas. La anchoveta desova por primera vez al completar su primer año y nuevamente a fines de su segundo año y, posiblemente, de su tercer año.

INTRODUCCION

La anchoveta *(Cetengraulis mysticetus)*, el más importante pez de carnada empleado en la pesca del atún en el Océano Pacífico Oriental Tropical, es obtenida por los pescadores en bahías y estuarios ampliamente separados dentro de la zona comprendida entre Baja California, México, y el Perú. La Comisión obtiene registros detallados de las cantidades pescadas en cada área productora de carnada y del esfuerzo empleado en pescar dichas cantidades (Alverson y Shimada, 1957). Estos registros de pesca ayudan a medir, y eventualmente a predecir, los cambios en la abundancia y rendimiento de estas poblaciones, pero su adecuada interpretación requiere el conocimiento de la historia natural y ecología de la especie. Gracias a la generosa cooperación de la flota atunera, desde 1951 la Comisión ha obtenido recolecciones de anchovetas de las áreas más importantes de carnada, las que han servido para los estudios de su biología e historia natural. Estas muestras han sido complementadas, siempre que ha sido posible, con las recolecciones hechas por el personal de la Comisión y por los pescadores locales en algunas de las áreas más lejanas.

Los estudios morfométricos y merísticos de las recolecciones representativas efectuados por Howard (1954) y Berdegué A. (1958) han demostrado que no hay un libre intercambio de anchovetas entre las áreas de carnada de mayor importancia y que las poblaciones probablemente constituyen unidades separadas. En consecuencia, las diversas poblaciones de anchovetas son tratadas separadamente para los estudios de su biología.

Además de las antes mencionadas investigaciones raciales, el propósito para el cual han sido usadas principalmente las recolecciones de anchovetas de los barcos atuneros es el de estudiar su edad, crecimiento, madurez sexual y desove. Para esto último se necesitan recolecciones de cada área durante todo el año; pero como las localidades productoras de carnada sólo son frecuentadas por la flota atunera cuando la pesca de atún es productiva en las áreas del mar adyacentes, se necesitan varios años para obtener las series de recolecciones requeridas para cada región. En realidad, no disponemos todavía de recolecciones que cubran todos los meses del año en la mayoría de las localidades de pesca.

Desde fines de 1954, la Comisión ha mantenido un laboratorio en Panamá para el estudio de la biología y ecología de la población de anchovetas del Golfo de Panamá. El personal del laboratorio ha recogido muestras de anchovetas para los estudios de la edad, crecimiento y desove. Estas recolecciones, junto con las que han hecho los barcos atuneros, nos proporcionaron una serie anual completa de datos de esta región mucho antes de haber reunido material adecuado de otra parte.

Los resultados de las investigaciones de la edad, crecimiento, madurez sexual y desove de la anchoveta en el Golfo de Panamá fueron publicados por Howard y Landa (1958). El presente estudio trata del conocimiento actual sobre estos aspectos de la historia natural de la anchoveta en otras áreas productoras de carnada. Estas regiones incluyen la Bahía de Almejas, Guaymas, Punta Ahome, Bahía Banderas, el Golfo de Fonseca, la costa de Colombia y las costas de Ecuador-Perú. Su localización geográfica se muestra en la Figura 1.

Las recolecciones de anchovetas para este estudio fueron hechas entre abril de 1951 y abril de 1960 en siete de las más importantes áreas de carnada del Pacífico Oriental Tropical y fueron 326 constituídas por 38,726 peces. Un detallado sumario del número de recolecciones y del número de especímenes capturados en cada área se encuentra en la Tabla 1.

METODOS

Los procedimientos técnicos que fueron empleados en este estudio de la edad, crecimiento, madurez sexual y desove son esencialmente los mismos que fueron descritos por Howard y Landa (1958) en su estudio de la población de la anchoveta en el Golfo de Panamá. Se usó un análisis de la frecuencia de las longitudes para determinar la edad y la tasa de crecimiento. El estudio de la madurez sexual y de la época del desove se basó en el examen macroscópico de los ovarios y en la aplicación del índice de gónadas que estos autores idearon. Se midieron las ovas de una región—el Golfo de Fonseca.

Edad y crecimiento

La lectura de las escamas o la interpretación de las marcas o bandas de áreas diferenciadas de otras partes duras no se tomaron en consideración para el análisis de la edad y el crecimiento. Howard y Landa pusieron de manifiesto que un examen de las escamas de la anchoveta sería difícil y consumiría mucho tiempo. Un examen posterior de las escamas de la anchoveta de Panamá, que efectuó Clifford L. Peterson (datos sin publicar), indicó que no tienen valor para la determinación de la edad, por lo menos en esta área. Se pensó que un estudio de otras partes duras, tales como los otolitos, no daría un mejor resultado. La aplicación del método de la frecuencia de las longitudes para determinar la edad y el crecimiento comprendió un estudio de la progresión temporal de los grupos de tamaños modales de los gráficos de las distribuciones mensuales de la frecuencia de las longitudes.

La longitud estándar de cada pez fué medida hasta el milímetro más cercano, de la punta del hocico al extremo del área plateada en el pedúnculo caudal. Las frecuencias para cada longitud en cualquier mes fueron combinadas y convertidas a porcentajes del total para el mes a fin de permitir la comparación con recolecciones de otros meses y de otras áreas. Los valores fueron graficados como distribuciones mensuales de los porcentajes de la frecuencia de las longitudes. Estas aparecen en las figuras. Los números en el lado derecho de cada panel indican el número de recolecciones y de especímenes medidos.

Las limitaciones impuestas en el empleo del método de la frecuencia de las longitudes para obtener estimaciones de la edad y el crecimiento de la anchoveta por efecto del traslapo de las distribuciones de las longitudes de los peces de más edad y por el empleo de muestras que posiblemente no son representativas debido a la agregación de los cardúmenes y a la pesca selectiva fueron tratadas en detalle por Howard y Landa (1958). Estas limitaciones en el empleo del método de la frecuencia de las longitudes son aplicables similarmente en este estudio; su uso fué aún más limitado por la aparición en algunas áreas de un desove irregular o prolongado, lo que a menudo modifica los máximos en las distribuciones de la frecuencia de las longitudes. Sin embargo, dentro de estas limitaciones, la técnica usada dió una estimación generalmente consistente de la edad y el crecimiento de la anchoveta.

La selección de tamaños por los pescadores de atún y el ambiente fuera de la costa en que habita la anchoveta juvenil reducen la efectividad de las recolecciones de esta especie hechas por los pescadores de atún para la estimación de la composición de edades de los stocks. Esto fué discutido detalladamente por Howard y Landa (1958). Sin embargo, siempre es de utilidad una estimación, aunque sea a *grosso modo,* de la proporción en que cada grupo de edad contribuye a la pesca en las más importante áreas de carnada.

Las distribuciones mensuales de los porcentajes de la frecuencia de las longitudes fueron estudiadas para determinar la presencia de modos y su significación; generalmente mostraron uno o dos modos que pudieron ser seguidos en serie (con interrupciones ocasionales) durante todo el año. Para cada área se anotó el mes que presentaba el grupo modal de peces de tamaño mínimo. Como se había demostrado que la anchoveta desova solamente una vez al año en cada una de las áreas (página 210) y como los peces más pequeños sólo estuvieron presentes por corto tiempo después del desove, estos peces pequeños tenían que representar el grupo de edad entrante ("grupo de edad" se usa para referirse a los peces de una edad determinada).

Un segundo grupo modal conteniendo peces más grandes fué encontrado frecuentemente concurrente con el grupo modal conteniendo peces más pequeños. En los meses subsiguientes hubo una progresión estable del primer grupo modal (que contenía peces en su primer año) hacia la derecha, hasta que este grupo formó por sí solo el segundo grupo modal en el año siguiente.

Fué relativamente fácil distinguir grupos modales representativos de peces en el primer año de los que contenían individuos en su segundo año, durante los primeros meses posteriores al reclutamiento, gracias a la diferencia comparativamente grande entre las longitudes de los peces en los dos grupos de edades. Con el tiempo, los peces del primer año crecieron tan rápidamente que a menudo no podía apreciarse una diferencia notoria entre los grupos modales; se observó una tendencia de los peces más grandes del grupo del primer año a traslapar los más pequeños del grupo del segundo año, haciendo difícil la separación de los dos. Se establecieron criterios arbitrarios para separar lo que obviamente era dos grupos de edades, como lo indicaban las amplitudes de los tamaños.

En muchos meses hubo un intervalo definitivo entre los dos grupos modales y entonces la separación fué simple. En donde no ocurrió un intervalo definitivo, la frecuencia más baja entre los dos puntos máximos se consideró que era el punto de división. En algunos meses hubo un cierto traslapo de las distribuciones para uno o dos meses, pero el conocimiento de la amplitud de tamaños de los grupos modales en los meses precedentes y subsiguientes sugirió donde se debía hacer la separación entre los grupos de edades. En ciertos meses sólo hubo un grupo modal y estos peces se consideraron en el primer o en el segundo año, de conformidad con su amplitud de longitudes. Debe hacerse notar que estas separaciones artificiales cortan el límite superior de los tamaños de los peces más jóvenes y el límite inferior de los tamaños de los peces de más edad. Howard y Landa (1958) demostraron que los criterios usados aquí para la separación de los grupos de frecuencias son tan racionales como los que comprenden el empleo del papel de probabilidad e igualmente válidos.

Después de separar los grupos de edades se determinó la longitud media y la amplitud de tamaños para cada grupo de edad en cada mes. Estos datos, lo mismo que las cantidades de peces en cada grupo de edad, fueron tabulados. Fué aparente alguna inconsistencia en el aumento ordenado de las longitudes medias de un mes a otro, debido a las deficiencias de la técnica empleada en el muestreo (página 191), pero hubo un consistente aumento temporal en las longitudes medias.

La falta de recolecciones o el pequeño número de especímenes en una recolección en algunos meses hizo difícil lograr una estimación consistente de la tasa de crecimiento de la anchoveta de las recolecciones de cada año. La época del desove y de la entrada de los peces jóvenes en la población sufre poca variación de un año a otro en la mayoría de las áreas. Para estas áreas, las frecuencias de los porcentajes de longitudes para cada mes para todos los años de recolección fueron combinadas y se sacó un promedio. Dichas frecuencias fueron graficadas para exhibir las distribuciones generales de los porcentajes de la frecuencia de las longitudes para todos los datos combinados por cada mes calendario durante el período completo de las recolecciones. La consolidación se hizo combinando las distribuciones de los porcentajes de las frecuencias en vez de las frecuencias propiamente.

Estas distribuciones de los porcentajes de la frecuencia de las longitudes para todos los años combinados fueron analizadas por el mismo método en que lo fueron para los meses individualmente. Los grupos de edades fueron separados y se calcularon las amplitudes de los tamaños y las longitudes medias. La consolidación de los datos indicó a menudo nuevos puntos de separación entre los grupos de edades. En consecuencia, las resultantes amplitudes mensuales de tamaños y las longitudes medias no concuerdan necesariamente con aquellas que resultarían al sumar y promediar las longitudes medias mensuales para todos los años.

El crecimiento de la anchoveta fué mostrado graficando las longitudes medias mensuales de los grupos de edades contra el tiempo. Las longitudes medias por mes para todos los años combinados y las longitudes medias por mes para cada año han sido graficadas para cada una de las áreas, cuando fué factible. Las líneas verticales delimitan la amplitud en longitud entre las anchovetas más pequeñas y las más grandes en cada mes para los datos de todos los años combinados.

Para las áreas en que las recolecciones fueron escasas (Colombia, Bahía Banderas y la zona Ecuador-Perú) sólo se presentan las distribuciones mensuales de los porcentajes de la frecuencia de las longitudes para todos los años combinados. Sin embargo, en las tablas sí aparecen los datos correspondientes a las recolecciones de cada mes.

Madurez sexual y desove

El estudio de la madurez sexual y del desove de la anchoveta se realizó para determinar la época y la duración del desove y los períodos en que éste alcanza el máximum en cada una de las áreas, la frecuencia del desove dentro de una estación en otra área que no fuera el Golfo de Panamá que fué examinada por Howard y Landa (1958) y las edades en el momento de la primera madurez y subsiguiente. Se emplearon técnicas analíticas similares a las de Howard y Landa.

Se retuvieron de 25 a 50 especímenes de muchas de las recolecciones para el estudio de la madurez y del desove. Se examinaron las gónadas de todos los peces disponibles. La apariencia de las gónadas ha sido descrita detalladamente por Howard y Landa. Los ovarios se midieron en el punto de su anchura máxima por medio de compases de división. En cuanto a los especímenes del Golfo de Fonseca, se examinó un pedazo del ovario de cada hembra para determinar la presencia de huevos distinguibles desde un tamaño mayor que 0.20 mm.; si se encontraban, se medían hasta 100 de estos huevos (Howard y Landa, 1958, página 455). No se tomaron medidas de los testes, pero cuando fué posible los machos fueron clasificados en tres categorías: inmaturos, maduros y gastados. En las recolecciones se anotó la presencia de peces demasiado inmaturos como para distinguir su sexo o de peces gastados.

Howard y Landa (1958) desarrollaron el siguiente índice de gónadas para indicar el desarrollo sexual de la anchoveta hembra en el Golfo de Panamá:

$$\text{Indice de gónadas} = \frac{\text{anchura de la gónada (mm.)} \times 10^2}{\text{longitud estándar del pez (mm.)}}$$

Estos autores demostraron que el valor del índice de gónadas está directamente relacionado con el desarrollo del ovario según la medida de la longitud media del huevo y que el desove alcanza su punto más alto cuando el promedio del índice de gónadas para la población está en su maximum.

La efectividad del uso de este índice de gónadas para la anchoveta de otras áreas fué probada y confirmada con material recogido en el Golfo de Fonseca (página 210). Sobre esta base fué aceptado el empleo del índice de gónadas para describir la madurez sexual y el desove en todas las áreas de pesca de carnada.

Tres clases de índice de gónadas fueron establecidas para describir los estados de la madurez sexual. Las clases fueron derivadas de la relación entre la estación de desove y el valor del índice de gónadas para la anchoveta en el Golfo de Panamá. El punto más alto del desove en el Golfo de Panamá es en noviembre y diciembre (Howard y Landa, 1958). Las anchovetas hembras con índice de gónadas mayor que los de la clase 6 fueron las que prevalecieron en la población del Golfo en esa época. Estos peces pueden ser considerados como los más avanzados sexualmente; cuando se encontraron en las recolecciones de las áreas que estudiamos aquí, se asumió que el desove estaba en progresso. En el Golfo de Panamá, el número de anchovetas con índice de gónadas en las clases 3 a 6 disminuyó con respecto al punto máximo alcanzado en noviembre, mientras que aumentó el número de anchovetas en la clase superior a 6. Estos peces pueden considerarse que se acercan al estado sexual más avanzado; su presencia en las poblaciones objeto de estudio fué tomada como indicación de un inminente desove. Las anchovetas con índice de gónadas cuyo valor era menor de tres fueron las que más abundaban en octubre, antes de que se registrara el punto máximo de la época de desove en el Golfo de Panamá. Estos peces pueden considerarse en proceso de maduración; su presencia en las recolecciones estudiadas aquí sirvió para indicar las primeras señales del desarrollo sexual. Las anchovetas cuyas gónadas presentaban la apariencia de filamentos delgados que no permitían determinar el sexo mediante el examen macroscópico fueron consideradas inmaturas.

Se consideró que la época del máximo desove era la de los meses en que alcanzaban un máximo el porcentaje en la población de hembras con índice de gónadas superior a 6. La duración de la época de desove se consideró que era entre la primera aparición de anchovetas muy cercanas a un estado avanzado de madurez sexual y la última aparición de estos peces en estados sexuales avanzados. Estas deducciones se apoyaron en la disminución del número de anchovetas inmaturas conforme se acercaba la época del desove y en el número de peces gastados al terminar esa época. El grado de madurez de los machos, determinado con sólo un rápido examen, contribuyó a corroborar esta evidencia. El período en que los peces más pequeños aparecen en la población ha servido como una indicación más de la época de desove.

La frecuencia del desove en una estación puede ser determinada por el estudio del número de subsiguientes camadas de huevos en maduración en un ovario. Cuando se agrupa el conjunto de las distribuciones de la frecuencia de las longitudes de las medidas de los huevos de las muestras de hembras en maduración, de conformidad con la posición del último modo en la distribución, un examen muestra el número de camadas de huevos en maduración (Clark, 1934). El procedimiento ha sido explicado también por Howard y Landa (1958) y se discute detalladamente en la página 210 en lo referente al Golfo de Fonseca.

La edad de la anchoveta en su primera madurez sexual y en las subsiguientes fué determinada mediante la comparación de las distribuciones de la frecuencia de las longitudes de las hembras sexualmente avanzadas (índice de gónadas 6 ó mayor) en un mes en que se registró el punto más alto del desove, junto con la distribución de la frecuencia de las longitudes de todas las anchovetas en el mismo mes, para todos los años combinados. Las deducciones en cuanto a las longitudes (y edades) de la parte de la población que desova en relación a las longitudes (y edades) de la población total fueron sacadas por el examen de las distribuciones.

RESULTADOS

Bahía de Almejas

Edad y crecimiento

Ciento nueve recolecciones con un total de 14,097 anchovetas se hicieron en la Bahía de Almejas de abril de 1951 a marzo de 1959 (Tabla 2). Todas fueron hechas por las tripulaciones de los barcos atuneros durante sus operaciones rutinarias de pesca de carnada. Las recolecciones se hicieron en todos los meses, con excepción de junio y julio. Las distribuciones de los porcentajes de la frecuencia de las longitudes para las recolecciones de cada mes (1951 a 1959) han sido graficadas en las Figuras 2 a 10. Las distribuciones han sido arregladas para que corran de agosto de un año a mayo del año siguiente. De inmediato se nota en las figuras las distribuciones extendidas, difusas y polimodales de la frecuencia de las longitudes, especialmente cuando los peces más pequeños están representados. Son ejemplo de ésto las distribuciones de febrero de 1952 a marzo de 1953 (Figura 4), de septiembre de 1954 a febrero de 1955 (Figura 6) y de septiembre de 1957 a mayo de 1958 (Figura 9). Esta confusión es menos aparente cuando las anchovetas más grandes están representadas (por ejemplo, septiembre de 1951 a febrero de 1952, Figura 3). También, en algunos años, la entrada de juveniles en la población ocurre en más de un período distinto en el año. Esto difiere de la situación en las otras áreas, por lo que se consideró algunas posibles causas de estas distribuciones anómalas.

Algunas de las recolecciones fueron hechas en la Bahía Magdalena, un cuerpo de agua que al norte está contiguo a la Bahía de Almejas, y es de creerse que la combinación de las recolecciones de la Bahía Magdalena y de la Bahía de Almejas produjera estas discrepancias. Sin embargo, al separar las muestras de las dos áreas y comparar sus distribuciones no se encontraron diferencias importantes entre ambas zonas. Mediante el examen de las recolecciones de cada lugar antes de que fueran combinadas para formar las muestras mensuales se investigó la posibilidad de que grupos separados espacialmente fueran muestreados. No se encontraron notorias diferencias entre las distribuciones de la frecuencia de las longitudes de las muestras individuales de cada área y las de las muestras combinadas.

Como veremos más adelante (página 198), la época del desove en el área de la Bahía de Almejas se extiende de agosto a febrero, alcanzando la actividad de reproducción sus puntos más altos probablemente en los períodos agosto-septiembre y diciembre-enero. La consecuente entrada de las anchovetas jóvenes en la población en diversos meses viene a ser una explicación adecuada de la confusión en las distribuciones. Esta es la razón por la que solamente fué posible un análisis general sobre la edad y el crecimiento de la anchoveta en la Bahía de Almejas.

En todos los meses se encuentran uno o más grupos modales. Aunque con frecuencia parezcan vagamente definidos, estos grupos modales sin embargo exhiben claramente una progresión serial que puede ser seguida en los meses subsiguientes. Estos grupos y progresiones tal vez pueden verse mejor en las recolecciones de 1952-1953 (Figura 4) en las que se notan con mayor claridad los efectos sobre las distribuciones de los dos períodos en los cuales el desove alcanza su maximum. La clarificación de la edad y el crecimiento de las anchovetas en estos años nos delineará algunos rasgos generales de ambos fenómenos en la Bahía de Almejas.

En la Figura 4, el grupo difuso de anchovetas pequeñas (53 a 84 mm.) que aparece por primera vez en septiembre de 1952 puede ser seguido en todos los meses hasta marzo de 1953, cuando los peces alcanzan una longitud de 107 a 125 mm. (parte no sombreada de la curva). Estos peces deben ser el resultado de un desove en julio-agosto, por lo que en marzo tienen ya unos 8 meses de edad. Un segundo grupo de anchovetas pequeños (longitud mínima, 47 mm.) que puede separarse arbitrariamente de las recolecciones de diciembre, es distinguible hasta marzo de 1953 cuando su longitud alcanza 78 a 106 mm. (parte sombreada de la curva, a la izquierda). Estos peces deben ser el resultado de un desove en noviembre-diciembre y, en consecuencia, tienen unos 4 meses de edad en marzo.

El grupo modal de anchovetas más grandes (93 a 119 mm.) en la recolección de septiembre de 1952 pueda ser seguido hasta marzo, cuando está representado por el grupo modal de tamaños entre 126 a 143 mm. (parte sombreada de la curva, a la derecha). Estos peces más grandes pueden ser o bien el resultado del máximo desove ocurrido en el verano del año anterior (1951) y tener unos 13 meses en septiembre, o bien el resultado del desove máximo del invierno y tener unos 9 meses en septiembre. Las anchovetas del desove del verano, que tienen 8 meses en marzo, varían de 108 a 125 mm., de modo que es razonable asumir que el grupo modal de peces de un tamaño más o menos igual en la recolección de septiembre se encuentra más cerca de los 9 meses que de los 13 meses de edad y es el resultado del desove del invierno anterior. Este grupo debe tener, entonces, 15 meses en marzo.

Tomando en cuenta lo anterior, se pueden hacer estimaciones aproximadas sobre la edad y el crecimiento de la anchoveta de la Bahía de Almejas. Los anchovetas cuya longitud varía de 115 a 140 mm. (longitud media, más o menos 127 mm.) tienen un año de edad; las que miden de 140 a 157 mm. (longitud media más a menos 146 mm.) tienen dos años de edad; y las de tamaños más grandes que ésto tres años o más. Estas cifras concuerdan con las de la edad y el crecimiento de la anchoveta de las otras áreas estudiadas.

Usando estas amplitudes de la longitud como criterio general para la edad de la anchoveta de la Bahía de Almejas, se han estimado las edades de algunos de los grupos modales más claramente definidos en las distribuciones. Estas edades han sido consignadas en las figuras; cuando no se indican, se presume que ha habido una mezcla de grupos de edades y no se han asignado edades particularmente. No se preparó una presentación tabular de las longitudes medias de cada grupo de edades de un mes a otro, ya que no tendría ninguna importancia dado el amplio margen de longitudes en los grupos de edades.

Madurez sexual y desove

El número de anchovetas examinadas para constatar su madurez sexual se da en la Tabla 3, por mes y año y para todos los años combinados; se examinaron especímenes de todos los meses en que se hicieron recolecciones. También se da en la Tabla 3 el número de hembras desovadas y el grado de madurez sexual de las anchovetas hembras según lo indicado por la clase de su índice de gónadas. Estos últimos datos, para todos los años combinados, se presentan gráficamente en la Figura 11.

En todos los meses de los años estudiados, excepto en diciembre, se encontraron en la población hembras desovadas, pero no en cada uno de los meses de cada año individualmente. En dos períodos en el año se hallaron en la población anchovetas hembras maduras (índice de gónadas superior a 6); se pescaron en diciembre (1956 y 1958), en enero y febrero (1952), y en agosto (1958), así como anchovetas machos también maduras. Igualmente se capturaron machos maduros en enero de 1959. Conjuntamente con las hembras maduras, en las recolecciones de diciembre, enero y febrero se encontraron hembras en proceso de maduración (índice de gónadas de 3 a 6). También en marzo, abril y mayo de 1958 se capturaron hembras en estas mismas condiciones de inminente madurez, siendo probablemente precursoras de las que desovaron en agosto de 1958. Anchovetas hembras inmaturas estuvieron presentes en la población en casi todos los meses del año, lo que puede ser una reflexión de la persistencia en la población de anchovetas juveniles en la mayor parte de los meses en todos los años, aunque no en cada uno de los meses de cada año individualmente.

Los datos disponibles sobre el tiempo de desove y la duración de la época de reproducción en el área de la Bahía de Almejas están sujetos a diversas interpretaciones. Las varias recolecciones de "invierno" y la única recolección de "verano" de anchovetas maduras podrían indicar un doble desove anual. La falta de adecuadas recolecciones de peces adultos en los meses intermedios (septiembre, octubre y noviembre) dificulta una conclusión definitiva. Sin embargo, el desove dos veces al año no parece probable ya que esto no sucede en las otras áreas estudiadas. Una segunda posible interpretación de los datos es que existe una extendida temporada de desove, de agosto a febrero. Las anchovetas de un tamaño menor de 60 mm. han sido recolectadas de agosto a febrero (excepto en noviembre) en 1952, 1954, 1955 y 1956 (Figuras 4, 6, 7 y 8), lo que indica la ocurrencia de un continuo desove. También se ha observado una extendida temporada de desove de la anchoveta en el Golfo de Fonseca. Junto con esta extendida época de desove en la Bahía de Almejas hay la probabilidad de dos períodos en que la actividad reproductora alcanza su punto más alto. Los peces pequeños (36 a 47 mm.) entraron en la población en agosto (1956), en septiembre (1955 y 1956), y en diciembre (1952), mientras que habiéndose hecho un razonable muestreo en otros meses durante este mismo período no se capturaron peces tan pequeños. También hay una bimodalidad en algunas de las distribuciones de la frecuencia de las longitudes de los peces en su primer año, sugiriendo la entrada en la población de dos grupos algo diferentes. Hasta donde hemos tenido evidencia, es probable que el desove se extienda de agosto a febrero en el área de la Bahía de Almejas, con períodos en agosto-septiembre y diciembre-enero en que la actividad reproductora alcanza su máximum.[1]

Las únicas hembras maduras recolectadas medían de 134 a 159 mm. de longitud, pero también se recolectaron hembras desovadas que medían entre 121 y 164 milímetros. Esta amplitud de tamaños incluye anchovetas de uno, dos y probablemente tres años de edad. Aparentemente, la anchoveta en la Bahía de Almejas, como en otras regiones, desova por primera vez al finalizar su primer año de vida y nuevamente en su segundo y tercer años.

---

[1] Después de terminado este estudio, el Sr. F. G. Alverson, científico de la Comisión, muestreó en agosto 12-17, 1960, en la Bahía de Almejas, anchovetas sexualmente maduras.

Guaymas

Edad y crecimiento

De abril de 1951 a mayo de 1957 se recolectaron 69 muestras en Guaymas, con un total de 8,887 anchovetas. El número de recolecciones hechas y la cantidad total de especímenes capturados en cada mes, para todos los años, figura en la Tabla 4. Todas las recolecciones fueron hechas por las tripulaciones de los barcos atuneros, excepto cuatro. El personal de la Comisión recolectó las muestras de agosto de 1956 y una de las cuatro recolecciones hechas en septiembre de 1956. Una de cada recolección de octubre y noviembre se hizo por los pescadores locales en Guaymas. Se hicieron recolecciones en todos los meses, excepto en diciembre. Las distribuciones de la frecuencia de las longitudes se muestran para cada año en las Figuras 12 a 18. Las distribuciones para los diversos años se han combinado por meses en la Figura 19.

Uno o más grupos modales están presentes en todos los meses. Estos grupos modales pueden ser seguidos de un mes a otro en la mayoría de los años. Esta progresión serial y la presencia de dos grupos modales se destacan en las recolecciones de 1952 y 1956 (Figuras 13 y 17). Ambos grupos de peces están presentes en febrero de 1952 y pueden ser seguidos hasta mayo; el grupo más pequeño persiste en junio, pero después de este mes no se obtuvieron más recolecciones. Grupos modales similares aparecen en 1956. El predominante, que representa los peces más pequeños en febrero, puede ser seguido en todos los meses hasta noviembre. El otro grupo modal de peces más grandes se manifiesta plenamente en abril y mayo. Un tercer grupo modal de anchovetas muy pequeñas aparece por primera vez en noviembre de 1956. En otros años grupos modales similares de peces pequeños hacen su primera entrada en enero.

Las anchovetas más pequeñas que fueron capturadas en septiembre y octubre de 1951 a 1957 medían 115 y 116 mm. (Figuras 15 y 17, Tabla 5). Como la anchoveta en Guaymas desova solamente una vez al año, registrándose en septiembre y octubre el máximum de su actividad reproductora (página 202), cualquier pez que sea encontrado con una longitud menor de 115 mm. unos dos a cinco meses después en noviembre (Figura 17) y en enero (Figuras 15 y 16) debe ser el resultado del desove en los meses inmediatamente anteriores. Las anchovetas que midan más de 115 mm. en este mismo tiempo deben de tener un año de edad o más.

Recolecciones en noviembre solamente se hicieron en el año 1956. El grupo modal cuya longitud fluctúa entre 46 y 73 mm. está formado por anchovetas en su primer año de edad. El grupo de peces más grandes (124 a 156 mm.) capturados en el mismo mes debe de tener un año o más. En 1954 y en 1955 solamente se recolectaron anchovetas en el mes de enero. Las recolecciones contenían peces entre 63 a 108 mm. y entre 46 a 87 mm., respectivamente; ambos grupos estaban formados por anchovetas en su primer año. Las recolecciones de febrero de 1952 y 1956 contienen dos grupos modales similarmente bien definidos cuya longitud varía, para los peces de un año, entre 63 a 126 mm., y para los de dos años o mayores, entre 129 a 151 milímetros. Iguales diferencias se manifestaron entre los dos grupos de edades para la mayoría de los otros meses y años.

Amplitudes considerablemente extendidas y distribuciones aparentemente bimodales fueron evidentes en las distribuciones de la frecuencia de las longitudes de algunas de las recolecciones de anchovetas en su primer año. Estas fueron particularmente notorias en las recolecciones de febrero de 1952, enero y marzo de 1954 y enero de 1955. El examen de la composición de las recolecciones mensuales reveló en algunos meses una variación considerable entre las muestras, lo suficiente para producir o bien una extendida amplitud de tamaños, o bien una distribución bimodal. En otros meses, una sola recolección exhibió una u otra de estas situaciones. Estas variaciones se deben probablemente a la extensión de la estación de desove y al resultante reclutamiento de anchovetas jóvenes en un período de varios meses. La agrupación por tamaños y el muestreo insuficiente pueden ser también factores causantes de estas variaciones. Aun para el Golfo de Panamá, en donde la estación de desove es más corta y el muestreo fué mejor, Howard y Landa (1958) observaron tales anomalías. La posibilidad de la existencia de subpoblaciones que contribuyan a causar estos efectos no puede ser evitada, pero no parece probable. La detallada comparación biométrica de Berdegué A. (1958) de las poblaciones de anchovetas no dió evidencia de subpoblaciones. Aun cuando se notaron algunas diferencias entre las recolecciones de las subáreas de la región de Guaymas, no fué aparente un patrón consistente. Howard y Landa (1958) no encontraron subpoblaciones en el Golfo de Panamá a pesar de contarse con recolecciones muchos más extensas.

En mayo y julio de 1951, junio de 1954 y septiembre, octubre y noviembre de 1956, no fué aparente una clara separación entre los peces en su primer año de vida y los que tenían uno a más años que éstos. Esto fué debido (con excepción de noviembre de 1956) a la consolidación de las recolecciones para formar compuestos. Las separaciones fueron aparentes en las muestras individuales. En estos meses los peces de un año fueron arbitrariamente separados mediante la aplicación de los criterios anteriormente descritos.

Cuando se combinaron los datos por mes para todos los años (Figura 19) se obtuvo un patrón serial completo del crecimiento (excepto para diciembre). Fué entonces más fácil separar los peces mayores de un año que en las distribuciones para los años y los meses individualmente considerados. Lo mismo que en las curvas de distribución para cada mes, estuvieron presentes amplitudes no usuales y distribuciones bimodales. Sin embargo, fué posible todavía separar las anchovetas en su primer año; estas separaciones están indicadas por flechas.

Los grupos modales de estas anchovetas en su primer año pueden ser seguidos desde su primera aparición en noviembre, con unos dos meses de edad, hasta octubre cuando entran en su segundo año. Dejando a un lado por el momento el grupo de los peces más grandes en noviembre, a juzgar por su amplitud de tamaños es evidente que los peces que forman los segundos grupos modales a la derecha en las recolecciones de febrero *et seq.* son una continuación en serie con los peces que entran en su segundo año en octubre; lógicamente estos peces también están en su segundo año. El segundo grupo modal de anchovetas en las recolecciones de octubre debe representar la anchoveta que entra en su tercer año. Los extendidos límites superiores de la amplitud en febrero, marzo, mayo y septiembre probablemente representan peces en su tercer año. Como la proporción de estos peces en las poblaciones es aparentemente pequeña, no se hizo el intento de separarlos de los peces en su segundo año. La única recolección de noviembre de 1956 de peces más grandes, que aparecen como un solo grupo modal, probablemente contiene peces de dos y tres años de edad. La anomalía probablemente resultó de un muestreo inadecuado y no se intentó la separación de los dos grupos de edades.

Las cantidades, amplitudes y longitudes medias de las anchovetas en los dos grupos de edades se dan en la Tabla 5 por mes para cada año y para todos los años combinados. La recolección anómala de noviembre fué convenientemente registrada como constituída por peces en su segundo año, pero no se calculó el promedio y los datos no fueron usados en el análisis.

Las longitudes medias de las anchovetas para todos los años combinados (círculos rellenos) y para cada año individualmente (círculos abiertos) y las amplitudes en longitud para todos los años combinados han sido graficadas en la Figura 20. Como en agosto sólo se capturaron 7 peces en su segundo año, no se indica la media para esta muestra aunque sí se da la amplitud. Las longitudes medias para todos los años combinados exhiben un bien definido patrón típico de crecimiento. La anchoveta en Guaymas crece rápidamente de noviembre a mayo (de una longitud promedio de 58 mm. a 124 mm.), pero de mayo en adelante crece despaciosamente hasta alcanzar una longitud media de 128 mm. al final de su primer año. La tasa de crecimiento es considerablemente más lenta en el segundo año. Al completar su segundo año en octubre, los peces alcanzan una longitud media de 141 mm., o sea un aumento de 13 milímetros.

La Tabla 6 indica que el 77.7 por ciento de las anchovetas capturadas en la región de Guaymas de 1951 a 1957 se encontraba en su primer año. La gran mayoría del 22.3 por ciento restante estaba en su segundo año. No fué posible distinguir la pequeña proporción de peces que se hallaban probablemente en su tercer año o más.

Madurez sexual y desove

Las cantidades de anchovetas examinadas para determinar la madurez sexual y la época de desove se dan en la Tabla 7 por mes de acuerdo al año y para todos los años combinados. Las hembras han sido tabuladas según el estado de la madurez sexual medido por tres intervalos de los valores del índice de gónadas. Las hembras desovadas se anotan separadamente.

Los datos para las hembras se presentan también gráficamente en la Figura 21.

Los datos están demasiado esparcidos en cada año para delimitar el período de desove en cualquier año. En todos los meses en que se efectuaron recolecciones, excepto mayo de 1956, se encuentran anchovetas hembras desovadas; consecuentemente su presencia no puede ser usada para deducir cuándo se opera el desove, a menos que ocurra en todo el año. No parece razonable sacar la conclusión de que la reproducción es continua porque el estudio de la edad y el crecimiento ha demostrado que el reclutamiento de anchovetas jóvenes no se efectúa en todo el año sino que comienza en noviembre y continúa tal vez durante tres o cuatro meses.

Al examinar en la Figura 21 el panel que contiene los datos combinados para todos los años, se encuentra que anchovetas hembras en su más avanzado estado de madurez (índice de gónadas superior a 6) aparecen continuamente desde julio hasta octubre; más del 30 por ciento de las anchovetas examinadas se econtraron en esta condición en julio y en octubre. En septiembre de 1956 se recogió una anchoveta hembra en proceso de desove. Durante el mismo período, una buena proporción de las hembras examinadas estaba en estado de inminente desove (índice de gónadas de 3 a 6). Una proporción substancial de esta última clase se encontró también en mayo y junio. De las hembras de una recolección hecha en mayo de 1951, el dos por ciento estaba en el estado más avanzado; no se encontraron peces en condiciones similares ni en mayo de 1956 ni en junio de 1954. Solamente en 1954 y en 1956 se recolectaron muestras en los meses de mayo y junio. Las hembras en proceso de maduración (índice de gónadas menor de 3) prevalecieron de abril a julio y después fueron desapareciendo gradualmente. Algunos pocos de estos peces fueron encontrados también antes de abril.

En la región de Guaymas el desove probablemente ocurre en su mayor parte en el período julio a octubre, alcanzando su máximum en septiembre y octubre, con una menor actividad reproductiva que algunas veces se presenta antes del mes de julio. En algunos años el desove continúa dentro de los meses de noviembre y diciembre, como lo indica la presencia de anchovetas pequeñas en las recolecciones de enero, febrero y marzo (Tabla 6). Los datos están demasiado esparcidos para determinar qué variación, si alguna hubiera, toma lugar de un año a otro y si hay o no diferencias entre las subáreas de la región de Guaymas. Las recolecciones de hembras maduras efectuadas en julio de 1951 en el área del Río Yaqui, pero no en el área del puerto de Guaymas, indican que el desove puede ocurrir más temprano en aquella área.

La distribución de la frecuencia de las longitudes de todas las anchovetas hembras avanzadas sexualmente (índice de gónadas de 6 o mayor) capturadas en Guaymas en octubre se compara en la Figura 27 con la distribución de la frecuencia de las longitudes de todas las anchovetas pescadas en Guaymas en dicho mes. Esta última distribución está constituída por grupos modales de un año y de dos años de edad (página 200). Las distribuciones coinciden lo que indica que la anchoveta en Guaymas desova por primera vez a la edad de un año y nuevamente a la edad de dos años.

Punta Ahome

Edad y crecimiento

De abril de 1951 a agosto de 1957, en las vecindades de Punta Ahome se hicieron 43 recolecciones con un total de 4,996 anchovetas (Tabla 8). En cualquiera de los años todas las recolecciones se hicieron de septiembre a diciembre. Las distribuciones de la frecuencia de las longitudes para las recolecciones de cada mes se muestran para cada año en las Figuras 23 a 28. Las distribuciones para todos los años combinados han sido graficadas en la Figura 29.

Uno o más grupos modales están presentes en todas las distribuciones. Estos grupos modales pueden ser seguidos por mes en casi todos los años conforme se mueven hacia la derecha. La progresión serial y la presencia de dos grupos modales se destacan en 1951 y en 1957 (Figuras 23 y 28). En 1951, el grupo modal predominante que aparece por primera vez en abril puede ser fácilmente seguido en los meses sucesivos hasta agosto. En julio y agosto se hacen presentes diferentes grupos modales secundarios de anchovetas más grandes. Grupos modales precursores, menos notorios pero igualmente bien definidos de estas anchovetas más grandes se observan como extensiones hacia la derecha de las distribuciones de la frecuencia de las longitudes del primer grupo modal en los tres meses precedentes. De modo similar, el extendido grupo modal que aparece en enero de 1957 (Figura 28) es aparente hasta mayo. El segundo grupo modal que aparece en febrero puede ser seguido hasta agosto. Los datos para otros años están esparcidos excepto en 1956 en donde son discernibles dos modos en febrero y marzo.

La anchoveta desova una vez al año en Punta Ahome; el maximum de la actividad reproductiva se registra en agosto (página 205). Los peces más pequeños capturados en una recolección de agosto medían 118 mm. (Figuras 23, 27 y 28; Tabla 9). Cualquier pez con una longitud menor de 118 mm. que aparezca en la población en enero necesariamente ha de ser el resultado del desove del verano y debe de estar en su primer año de vida. Similarmente, los peces de más de 118 mm. tienen uno a más años de edad. (Se recuerda al lector que no se efectuaron recolecciones de septiembre a diciembre). Estos grupos de edades fueron fácilmente discernibles en todas las recolecciones en que aparecían. La separación de los peces de un año de edad se indica por flechas en las figuras; los números, amplitudes y longitudes medias por mes para cada año y para todos los años combinados se dan en la Tabla 9.

Por la evidencia de que disponemos, las anchovetas en Punta Ahome desovan una vez al año y la reproducción probablemente ocurre más o menos en el mismo período entre junio y agosto de cada año (ver página

205). La combinación de todos los datos de la frecuencia de las longitudes por mes para todos los años está probablemente bien justificada para obtener un mejor cuadro del crecimiento y del número de los grupos de edades. La Figura 29 y la Tabla 9 nos proporcionan este cuadro. En casi todos los meses se encontraron dos distintos grupos de edades. Estos grupos corresponden a los peces en su primer año de vida y a los del segundo año o mayores. Puede observarse una separación bien notoria entre los grupos excepto en mayo y en agosto. En estos meses los dos grupos fueron separados arbitrariamente sobre la base de la longitud máxima de los peces que forman parte del grupo de edad más joven en los meses precedentes y posteriores.

El grupo modal constituído por los peces más grandes aparentemente es de un solo grupo de edad predominantemente. Tanto por los datos combinados como por los de para cada año no hay mucha sugerencia de que haya presente más de un solo grupo de edad, aunque existe la posibilidad de que unos pocos peces sean un año mayor que los otros en este grupo; estos son los pocos que aparecen como individuos aislados en la extensión superior de la amplitud de las longitudes en ciertos meses. Quedan incluídas las anchovetas de 157, 159 y 160 mm. de enero de 1952, y de 160 y 162 mm. de marzo de 1957. Sin embargo, para todos los fines prácticos, la población de Punta Ahome, según lo indican las muestras disponibles, está constituída por sólo dos grupos de edades. Los números, amplitudes y longitud media de este segundo grupo por mes para cada año y para todos los años combinados se dan en la Tabla 9.

Las longitudes medias mensuales para todos los años combinados (círculos rellenos) y para cada uno de los años (círculos abiertos) y las amplitudes en longitud para todos los años combinados han sido graficadas en la Figura 30 para dar un cuadro de la tasa de crecimiento. Este es rápido de enero a marzo (91 mm. a 117 mm.) pero después de marzo es más lento. Al final del primer año, estos peces alcanzan una longitud de más o menos 130 mm.; un año más tarde se acercan a los 150 milímetros.

Alrededor del 80 por ciento de las muestras de anchovetas recolectadas por los pescadores en Punta Ahome entre 1951 y 1957 se encontraban en su primer año de vida (Tabla 6).

Madurez sexual y desove

Las anchovetas de Punta Ahome fueron examinadas para la determinación de la madurez sexual para todos los meses en que se hicieron recolecciones. Los números examinados de acuerdo con las épocas de captura se dan en la Tabla 10 para las recolecciones de cada mes y para todos los años combinados. También se ha registrado el grado de madurez sexual de las anchovetas hembras según lo indica el índice de gónadas, y el número de hembras desovadas. Estos últimos datos, por mes y para todos los años combinados, se presentan gráficamente en la Figura 31.

Lo mismo que en Guaymas, en todos los meses en que se obtuvieron recolecciones estuvieron presentes hembras desovadas. Nuevamente, su presencia no es una indicación de la época de desove. El muestreo no permitió usar los datos para cada año individualmente para delimitar el período de reproducción (Tabla 10). El muestreo más completo se efectuó en 1951 cuando se obtuvieron recolecciones de abril a agosto. Solamente en junio, julio y agosto se encontraron hembras en estados avanzados de madurez sexual (índice de gónadas superior a 6). También se encontraron hembras en condiciones similares en los mismos meses de otros años en los cuales se hicieron recolecciones, excepto en agosto de 1957 cuando se encontró que las cinco hembras estudiadas estaban desovadas. Una de las seis hembras examinadas en mayo de 1956 estaba también en estado de avanzada madurez sexual. En julio y agosto, las anchovetas hembras de avanzada madurez predominaron por lo general sobre otras categorías. La presentación compuesta en la Figura 31 proporciona el mejor cuadro general. La situación es muy similar a la de Guaymas hasta agosto, pero desgraciadamente no se hicieron recolecciones en Ahome en los meses de septiembre y octubre. Como aparentemente no hubo disminución en la proporción de hembras avanzadas sexualmente en agosto con respecto a julio, es razonable la conclusión de que el desove continúa dentro de septiembre y tal vez aún por más tiempo como sucede en Guaymas (hasta diciembre).

La distribución de la frecuencia de las longitudes de las 53 hembras maduras (índice de gónadas de 6 o mayor) cogidas en agosto de todos los años en Punta Ahome ha sido graficada en la Figura 22. En esta figura se ha superpuesto la distribución de la frecuencia de las longitudes de todas las anchovetas capturadas en agosto en todos los años. Ambas distribuciones coinciden muy cercanamente y las hembras maduras están representadas en ambos grupos de edades de la población. Aparentemente la anchoveta en Punta Ahome desova por primera vez en su primer año y nuevamente en el segundo año.

Bahía Banderas

Edad y crecimiento

De mayo de 1952 a abril de 1956 se hicieron en la Bahía Banderas 22 recolecciones con un total de 2,211 anchovetas (Tabla 11). Todas las recolecciones fueron hechas en los cinco primeros meses del año por miembros de las tripulaciones de los barcos atuneros.

Por el hecho de que las recolecciones fueron muy dispersas a través de los años, no se han graficado las distribuciones de la frecuencia de las longitudes para las recolecciones de cada mes en cada año, pero sí se graficaron las distribuciones para todos los meses combinados (Figura 32). Las amplitudes de los tamaños y las longitudes medias de las recolecciones de cada mes (por clases anuales) y para todas las recolecciones combinadas se dan en la Tabla 12.

Inspección de la Figura 32 muestra la presencia de dos distintos grupos modales. Un grupo modal de peces más pequeños está presente en la población durante los meses de marzo, abril y mayo; el otro, de peces más grandes, aparece en enero, febrero, marzo y abril. Solamente en marzo (1954 y 1956) y en abril (1954 y 1955) se encontró que las recolecciones contenían ambos grupos de tamaños.

Los pescados más pequeños capturados en enero y febrero medían 98 y 102 milímetros. Los grupos modales constituídos por anchovetas de dimensiones menores fueron cogidos en marzo *et seq.*, indicando la probable entrada de un nuevo grupo de edad en la población. El estudio de la madurez sexual (página 207) sugiere indirectamente que el desove en la Bahía Banderas se opera en los últimos meses del año; la aparición de anchovetas pequeñas en los primeros meses respalda esta creencia. Así mismo, con base en las tasas de crecimiento en otras áreas, la longitud media de los peces de este grupo, unos 87 mm., indica que tienen unos tres meses de edad. Los peces que contribuyen a formar el grupo modal de ejemplares más pequeños aparentemente se encuentran en su primer año.

Como solamente disponemos de recolecciones de enero a mayo, no es posible seguir ordenadamente el crecimiento de los peces mientras no llegan a formar el segundo grupo modal en el siguiente año. Las diferencias en las longitudes medias entre anchovetas de 3 y 15 meses de edad en otras áreas son de 31 a 49 milímetros. La diferencia en la longitud media entre anchovetas en los dos grupos modales encontrados en marzo en Bahía Banderas es 38 mm., que está dentro de la amplitud de las diferencias en las otras áreas. Es probable que los peces que forman el segundo grupo modal estén en su segundo año de vida.

La evidencia de que disponemos, aunque se reconoce es inadecuada, sugiere que las anchovetas en la Bahía Banderas son considerablemente más pequeñas que las de otras áreas a la misma edad. Se asume que los peces capturados en enero de 1956 tienen por lo menos 13 meses de edad. La longitud media de las anchovetas en esta recolección es de 115 mm.; la longitud media de los peces de esta edad en otras áreas es más o menos de 125 a 130 milímetros. Peces comparablemente pequeños contribuyeron a formar los modos representando anchovetas en su segundo año en las recolecciones de 1954 y 1955, lo que indica que el tamaño más pequeño no es peculiar de las recolecciones de 1956.

Alrededor del 84 por ciento de las anchovetas capturadas en la Bahía Banderas se encontraban en su primer año (Tabla 6).

Madurez sexual y desove

Las anchovetas que medían entre 90 y 130 mm. fueron examinadas para determinar su madurez sexual. Los peces examinados incluían especímenes de ambas clases de edad y fueron de todos los meses en que se hicieron recolecciones. Todos los ejemplares examinados estaban sexualmente inmaturos; no fué posible ni siquiera determinar su sexo. No se encontraron peces gastados.

El desove en la Bahía Banderas debe ocurrir en cualquier época entre junio y diciembre. La apariencia del grupo modal de peces más pequeños en marzo sugiere que el período del desove está más cercano a diciembre que a junio. La presencia en los mismos meses, en cada uno de los cuatro años en que se hicieron recolecciones, de un grupo de peces más pequeños del mismo tamaño indica que hay consistencia en el período anual del desove.

Golfo de Fonseca

Edad y crecimiento

De mayo de 1951 a septiembre de 1955 se hicieron en este golfo 27 recolecciones con un total de 2,588 anchovetas (Tabla 13). Todas las recolecciones fueron hechas por tripulaciones de los barcos atuneros. En ninguno de los años se hicieron recolecciones en el período de octubre a marzo, excepto por una sola que se hizo en diciembre de 1951.

Las distribuciones de la frecuencia de las longitudes para cada mes de cada año se dan en las Figuras 33 a 36. Las recolecciones anotadas como de julio-agosto, 1951, fueron realizadas en julio 30, agosto 2 y agosto 4. Los datos para todos los años combinados aparecen en la Figura 37. Los datos de las recolecciones correspondientes a julio y agosto para todos los años han sido combinados de modo que las muestras de julio-agosto de 1951 puedan ser propiamente incluídas.

Las figuras muestran uno o más grupos modales que pueden ser seguidos en casi todos los meses de cada año. En 1951, el grupo modal que aparece en mayo puede ser seguido hasta diciembre (Figura 33). Otro grupo modal de peces más grandes es aparente en la recolección de agosto. Los pocos peces de tamaño más pequeño capturados en mayo, junio y julio-agosto probablemente representan un tercer grupo modal. El grupo modal de peces más pequeños que apareció por primera vez en abril de 1952 (Figura 34), puede ser seguido hasta junio. En junio se hacen presentes dos grupos modales de peces más grandes; estos reaparecen en la recolección de agosto. Un grupo modal puede verse en julio, agosto y septiembre de 1954 (Figura 35); algunos peces más pequeños en agosto y septiembre parecen representar otro grupo modal. En junio de 1955 (Figura 36) se hacen presentes tres grupos modales. Los dos grupos modales en septiembre probablemente representan los dos grupos de peces más grandes en junio. Sin embargo, el número de los peces en referencia es pequeño.

Aun cuando la separación en tres grupos modales es clara, la designación de los grupos de edades no lo es. Esto se debe principalmente a que no se hicieron recolecciones de peces juveniles, a pesar de que podía esperarse se encontraran en la población después del período del desove máximo en septiembre y posteriormente (página 209). Sin embargo, cuando se combinan y grafican los datos de todos los años, excepto 1952 (Figura 37), pueden sacarse algunas conclusiones en cuanto a los grupos de edades. No obstante, las distribuciones de la frecuencia de las longitudes de las recolecciones de 1952 han sido graficadas separadamente en la

Figura 37 (líneas de puntos) porque en las recolecciones de abril, mayo y junio difirieron de las de todos los otros años. Sin embargo, el análisis de los grupos de edades está basado en la combinación de los datos para todos los años, incluyendo 1952.

La anchoveta desova solamente una vez al año en el Golfo de Fonseca; el punto máximo de la actividad reproductiva se registra en septiembre y probablemente más tarde. La anchoveta más pequeña capturada en septiembre medía 129 mm.; y en diciembre, 128 milímetros. Cualquier pez de un tamaño más pequeño que aparezca en la población después de ésto probablemente ha resultado de este desove y está en su primer año de vida. En consecuencia, todas las recolecciones de abril de 1952 y la mayoría de las de mayo y junio del mismo año están constituídas por peces en su primer año. Los peces en el primer grupo modal, de aproximadamente los mismos tamaños en los mismos meses en los otros años, probablemente se encuentran también en su primer año. La separación de los peces de un año se indica por flechas en las figuras. Sus números, amplitudes y longitudes medias por mes para cada año y para todos los años combinados se dan en la Tabla 14. Solamente en 1952 se capturaron cantidades substanciales de anchovetas de un año de edad.

El número limitado de meses para los que tenemos colecciones impide seguir la progresión del primer grupo modal hasta que forma el segundo grupo modal un año más tarde cuando la clase anual entrante hace su aparición. En vista de situaciones similares en otras áreas, solamente podemos suponer que los peces más grandes que forman el segundo grupo modal están en su segundo año de edad. Limitaciones similares influyen en la designación de la edad de los peces en el tercer grupo modal; se asume que éstos están en su tercer año. La separación de estos dos grupos de edades se señala con flechas en las figuras. Los números, amplitudes y longitudes medias de estos peces por mes para cada año y para todos los años combinados se dan en la Tabla 14. (En septiembre y diciembre, algunos peces más pequeños han sido incluídos con los que están en su segundo año a pesar de que su tamaño sugiere que probablemente están en su primer año. Sin embargo, debido a la configuración de las distribuciones de la frecuencia de las longitudes no fué posible separarlos. En la Figura 22, en donde se ha graficado la distribución de la frecuencia de las longitudes de las anchovetas hembras maduras pescadas en septiembre aparece una interrupción en los 137 milímetros. Es probable que ésta se halle más cerca del límite superior real de las amplitudes de los peces en su primer año en aquel mes. Así se ha marcado en la Figura 22).

Las longitudes medias mensuales para todos los años combinados (círculos rellenos) y para cada uno de los años (círculos abiertos), lo mismo que las amplitudes para todos los años combinados se han graficado en la Figura 38 para presentar un cuadro de la tasa de crecimiento. El punto en septiembre (peces en su primer año) y el punto en diciembre (peces en su cuarto año) representan cada uno un espécimen. El crecimiento es aparentemente rápido en el primer año hasta julio y agosto, pero de allí en adelante es más lento. Al final de su primer año, la longitud media es probablemente de 125 a 130 mm.; un año más tarde, de 140 a 145 mm.; y al terminar su tercer año, de unos 160 milímetros.

Alrededor del 55 por ciento de las anchovetas pescadas en el Golfo de Fonseca se encontraban en su segundo año y más o menos un 12 por ciento en su tercer año (Tabla 6). Esto representa una proporción mayor de peces de dos y tres años de edad que los que han sido pescados en cualquiera de las otras áreas excepto los peces de dos años en Colombia.

Madurez sexual y desove

En la Tabla 15 se dan los números de anchovetas del Golfo de Fonseca examinadas para la determinación de su madurez sexual, por año y mes en que fueron capturadas y para todos los años combinados. Se incluyen también en dicha tabla el grado de madurez de las anchovetas hembras, según lo indica el índice de gónadas, y el número de hembras desovadas. Estos últimos datos aparecen en la Figura 39 para cada uno de los años y para todos los años combinados.

La madurez sexual y el desove de la anchoveta en el Golfo de Fonseca se investigó mediante el empleo del índice de gónadas; además, se midieron las ovas. Los datos se usaron para probar la efectividad del empleo del índice de gónadas para las anchovetas procedentes de otra región fuera del Golfo de Panamá. Howard y Landa (1958) demostraron que la anchoveta en el Golfo de Panamá desova solamente una camada de huevos en una estación. Los datos sobre las medidas de las ovas de las anchovetas del Golfo de Fonseca fueron también analizados para determinar si esto mismo ocurre con las anchovetas de otras áreas.

Epoca del desove

En todos los meses en que se hicieron recolecciones, excepto en julio de 1951 (Figura 39), se encontraron anchovetas hembras desovadas. Su presencia no puede ser utilizada para deducir cuándo ocurre el desove. En las recolecciones de septiembre (1954 y 1955) se encontraron hembras maduras. En junio (1955), julio (1951) y agosto (1951 y 1954) se encontraron hembras en proceso de maduración. En todos estos meses y en mayo de 1951 hallamos peces inmaturos pero con ovarios identificables. El examen en diciembre de 1951 de los ovarios de 16 hembras desovadas indica que algunas podrían haber desovado recientemente. Uno de los ovarios examinados se consideró que estaba en proceso de desove; otros sólo se encontraron parcialmente desovados. Cuatro de los machos examinados estaban maduros.

El desove se opera en el Golfo de Fonseca desde septiembre y probablemente hasta diciembre, con alguna actividad antes de septiembre. Como se hizo notar al referirnos a la edad y al crecimiento, no hay una evidencia corroborativa de la aparición de peces pequeños dos o tres meses después por la falta de recolecciones en octubre y noviembre y porque la única muestra de diciembre estaba constituída por peces más grandes. La presencia en la población de hembras maduras deja poca duda en cuanto al período del desove máximo o de su cercanía. La falta de datos en los meses inmediatamente subsiguientes no permite determinar con seguridad por cuánto tiempo puede continuar.

La distribución de la frecuencia de las longitudes de todas las hembras sexualmente maduras (índice de gónadas de 6 o más) capturadas en el Golfo de Fonseca en septiembre se compara en la Figura 22 con la distribución de la frecuencia de las longitudes de todas las anchovetas pescadas en septiembre en dicho Golfo. Esta última distribución está hecha por grupos modales de peces de uno, dos y tres años de edad. Ambas distribuciones coinciden. La anchoveta del Golfo de Fonseca desova por primera vez cuando tiene un año de edad, nuevamente a los dos años y otra vez cuando está en su tercer año.

Frecuencia del desove en una estación

Por el estudio de las camadas sucesivas de los huevos que maduran en un ovario es posible determinar la frecuencia del desove en una estación. Cuando se grafican las distribuciones de la frecuencia de las longitudes de las medidas de los huevos de todos los peces agrupados de acuerdo con la posición del último modo en la distribución de la frecuencia de las longitudes de los huevos de cada pez (Figura 40), se ve un cuadro en conjunto que muestra el crecimiento de las ovas hasta la madurez. Se seleccionaron 10 intervalos iguales de longitud para la posición del último modo entre 0.20 y 0.69 milímetros. Se indica el número de peces incluídos en cada grupo. No se encontraron ovarios con el grupo modal más grande de huevos de 0.20 a 0.24 mm. y de 0.30 a 0.34 milímetros.

El panel superior de la Figura 40 representa la distribución de la frecuencia de las longitudes de los huevos de los ovarios menos maduros. Conforme el ovario madura se hace aparente un solo grupo modal de huevos grandes (paneles subsiguientes). La progresión de este grupo hacia la derecha indica el desarrollo de estos huevos hacia su madurez. Mientras el ovario madura no se desarrolla un segundo grupo modal de huevos más pequeños, lo que indica que la primera camada de huevos no es reemplazada por otra. Está claro que las anchovetas hembras en el Golfo de Fonseca solamente desovan una camada de huevos en una estación.

La Figura 40 es esencialmente similar a la Figura 11 de Howard y Landa (1958) para la anchoveta en el Golfo de Panamá. Aparentemente, las anchovetas hembras del Golfo de Fonseca no son diferentes de las del Golfo de Panamá en cuanto a que solamente desovan una camada de huevos en un período de desove. Esto mismo probablemente puede decirse con respecto a las anchovetas de las otras regiones.

Relación entre el índice de gónadas y la madurez sexual

Las longitudes medias de los huevos de 0.20 mm. o más grandes han sido graficadas contra el respectivo índice de gónadas de 59 anchovetas hembras de todas las clases de edades y de todos los años (Figura 41). Una regresión rectilínea del cuadrado medio se ajusta a los datos $y=0.2984+0.0248\,x$). La prueba de F no demostró un apartamiento significativo de la linearidad al nivel del uno por ciento o del cinco por ciento.

Como la anchoveta debe de desovar cuando el huevo alcanza un tamaño máximo, el índice de gónadas (relacionado linearmente como está con el tamaño del huevo) resulta una indicación útil del grado de madurez sexual. Howard y Landa (1953) también encontraron tal relación para la anchoveta del Golfo de Panamá. El índice de gónadas parece ser un indicador efectivo del grado de madurez sexual de la anchoveta hembra.

Colombia

Edad y crecimiento

A lo largo de la costa de Colombia, de Buenaventura a Tumaco, entre julio de 1951 y agosto de 1959 se cogieron 25 muestras con un total de 1,709 anchovetas (Tabla 16). Las recolecciones de 1951 a 1955 fueron hechas por las tripulaciones de los barcos atuneros; las de 1957 por el personal de la Comisión usando red de arrastre, y las correspondientes a 1958 y 1959 las hicieron pescadores locales cerca de Tumaco usando red lámpara, atarraya y red de arrastre.

Tomando en consideración la pequeñez de algunas recolecciones y el hecho de haber sido realizadas esporádicamente, no se graficaron las distribuciones de la frecuencia de las longitudes de las recolecciones mensuales individuales. Sin embargo, en la Tabla 17 se dan (por grupos de edades) los datos correspondientes a las recolecciones. Las distribuciones de la frecuencia de las longitudes para todos los años combinados aparecen graficadas en la Figura 44 con base en los datos que también se dan en la Tabla 17.

Un grupo modal de peces con una longitud media de 127 mm. estuvo presente en las recolecciones de febrero. Este grupo puede ser seguido en marzo y en abril (Figura 42). El grupo modal en la pequeña recolección de agosto representa un ligero avance en la progresión de este grupo.

Excluyendo (por el momento) las 14 anchovetas pequeñas (longitud media, 41 mm.) cogidas en abril de 1959, un segundo grupo modal de peces más pequeños que los capturados en febrero *et seq.* apareció en las recolecciones de abril. Este grupo puede ser también identificado en las recolecciones de julio y octubre-noviembre. Unos pocos peces de este grupo fueron también cogidos en las recolecciones de marzo de 1957 y de agosto de 1959.

La extendida amplitud de las longitudes de la recolección de junio indica la inclusión de ambos grupos modales. El punto divisorio entre estos grupos fué situado en los 137 milímetros. Las otras divisiones entre los dos grupos de peces están señaladas con flechas (Figura 42).

El pez de tamaño más pequeño encontrado en las recolecciones de febrero medía 107 milímetros. La anchoveta desova una vez al año y, en la región de Colombia, generalmente en los últimos meses del año (página 213). En consecuencia, las anchovetas cogidas tres o cuatro meses después y de menos de 107 mm. deben de ser el resultado del desove previo. Los cuatro peces más pequeños en marzo y todos los ejemplares con una longitud de menos de 109 mm. capturados en abril deben de encontrarse en su primer año.

A pesar de que las recolecciones no están completas, es posible seguir en forma continua el grupo modal que contiene peces en su primer año de edad conforme progresa hacia la derecha para formar el segundo grupo modal un año más tarde cuando la clase anual entrante hace su aparición.

En abril de 1959 se hizo una gran recolección en Tumaco de juveniles de arenques de hebra *(Opisthonema libertate)*. En esta recolección se encontraron 14 anchovetas juveniles (entre 27 y 54 mm.), más pequeñas que cualquiera de las anchovetas encontradas anteriormente en marzo o abril en aguas frente a Colombia. Estas pequeñas anchovetas deben de ser el resultado de un desove atrasado en el área de Colombia en 1959. En ninguna de las recolecciones de otros años hechas en el mes de abril se capturaron anchovetas de estos tamaños.

Los números, amplitudes y longitudes medias de las anchovetas en los dos grupos de edades se dan en la Tabla 17 por mes para cada año y para todos los años combinados. Los peces en su primer año miden alrededos de 126 mm. y al final de su segundo año unos 142 milímetros.

Cerca del 59 por ciento de los peces cogidos en aguas frente a Colombia (Tabla 6) se encontraban en su segundo año. Esta proporción es la más alta que en cualquiera otra área.

Madurez sexual y desove

Las anchovetas de Colombia fueron examinadas para determinar la madurez sexual para todos los meses en que se hicieron recolecciones. Los números examinados de acuerdo con la época de captura se dan en la Tabla 18 para las recolecciones de cada mes y para las de todos los años combinados. El grado de madurez sexual de las anchovetas hembras según la indicación de su índice de gónadas y el número de hembras desovadas ha sido registrado. Estos últimos datos por meses para todos los años combinados se presentan gráficamente en la Figura 43.

En junio y julio se encontró un alto porcentaje de anchovetas hembras inmaturas pero identificables. En octubre y noviembre el desove estaba en progreso. El 67 por ciento de las hembras examinadas se encontraba en un estado avanzado de madurez; en esos meses se cogieron también anchovetas hembras menos avanzadas sexualmente pero en obvio proceso de maduración.[1] El desove continuaba todavía en progreso en febrero; el 42 por ciento de las anchovetas hembras estaban sexualmente maduras y también se capturaron hembras en menor estado de madurez pero madurando. En los meses de marzo y abril todas menos una de las hembras examinadas estaban ya desovadas. En marzo y abril se hicieron recolecciones de anchovetas pequeñas (27 a 109 mm.) en su primer año de vida. El desove en aguas frente a Colombia parece comenzar en octubre y continúa hasta febrero. El período de máximo desove no puede ser determinado basándose en estos datos.

---

[1] Una recolección hecha en Tumaco de septiembre a noviembre en 1959 contenía anchovetas machos y hembras sexualmente maduras, lo que ofrecía una mayor evidencia respecto a la época del desove. Estos datos no han sido incluídos en las tablas ni en las figuras.

La amplitud de la longitud de las hembras maduras era de 120 a 134 mm., que incluía anchovetas en ambos grupos de edades. La anchoveta en Colombia desova por primera vez en su primer año y nuevamente en su segundo año.

Ecuador-Perú

Edad y crecimiento

De septiembre de 1951 a abril de 1960 se hicieron a lo largo de las costas de Ecuador y Perú 31 recolecciones con un total de 4,238 anchovetas (Tabla 19). Las recolecciones en 1951 y 1952 solamente se hicieron en el Golfo de Guayaquil durante operaciones rutinarias de los barcos atuneros para proveerse de carnada. En 1952, el Golfo de Guayaquil fué cerrado para la pesca de peces de carnada y no se hicieron más recolecciones hasta 1958 cuando el personal de la Comisión las reanudó en Manta, Ecuador, y en el Golfo de Guayaquil. Desde 1958 se han hecho también recolecciones en Los Organos, Punta Sal y Paita, Perú, con atarrayas y redes de arrastre y de playa. Se recogieron muestras en todos los meses excepto en febrero y julio.

Debido a la escasez de los datos, las recolecciones mensuales en todos los años y áreas fueron combinadas y se graficaron las distribuciones de la frecuencia de las longitudes (Figura 44). El origen de las recolecciones se indica en la figura; las áreas rotuladas en bastardilla corresponden a la parte sombreada de las distribuciones. No se obtuvieron diferencias sobresalientes en la distribución en las diversas áreas, de modo que la combinación parece válida; algunas discrepancias son debidas probablemente a la extensión del período de desove (página 215). No se graficaron las distribuciones de la frecuencia de las longitudes de cada mes, pero los datos correspondientes a las recolecciones de cada mes se dan en la Tabla 20.

Uno o más grupos modales están presentes en todas las distribuciones. Los grupos modales pueden ser seguidos en casi todos los meses conforme se mueven hacia la derecha. El grupo predominante de anchovtas más pequeñas, que aparece por primera vez en marzo, puede ser seguido fácilmente en los meses sucesivos hasta enero. En marzo, abril, diciembre y enero se encuentran diferentes grupos modales secundarios de anchovetas más grandes. Algunos peces de tamaños más grandes en las recolecciones de septiembre-octubre y noviembre también representan este segundo grupo modal. Además, en marzo, la extendida distribución hacia la derecha indica la continua presencia de estos peces más grandes que forman un tercer grupo modal con la entrada del grupo modal entrante constituído por peces más pequeños.

La anchoveta desova una vez al año en esta área; el máximum de la actividad reproductiva se registra en diciembre y enero (página 215). Los peces más pequeños cogidos en las recolecciones de diciembre y enero medían 102 y 105 mm. (Figura 44, Tabla 20). Cualquier pez de una longitud menor que aparezca en la población en marzo y abril debe de ser el resultado de este desove. De igual modo, los peces más grandes tienen un año o más de edad. (En las recolecciones de marzo se encontraron peces con una amplitud de 110 mm., y en las recolecciones de marzo, abril y mayo es evidente alguna bimodalidad en las distribuciones de los peces más pequeños; estas anomalías pueden ser atribuídas a una extendida estación de desove en el área. Todas estas anchovetas se consideraron que estaban en su primer año). Los grupos de edades fueron discernibles en todas las recolecciones en que aparecieron. En la Figura 44 se indica con flechas la separación de los peces de un año de edad. Sus números, amplitudes y longitudes medias aparecen en la Tabla 20 por mes para cada año y para todos los años combinados.

Los grupos modales constituídos por peces más grandes son predominantemente de un grupo de edad, excepto en marzo cuando los peces de más de 134 mm. representan probablemente otro grupo de edad. Las anchovetas entre 121 y 134 mm. en marzo aparentemente han entrado en su segundo año de vida porque se mantienen en la continuidad de la serie con el grupo modal predominante de peces que completan su primer año en enero. El grupo modal de las anchovetas de mayor tamaño (134 a 147 mm.) en marzo es continuo con el grupo modal de anchovetas que completan su segundo año en enero y aparentemente se encuentran en su tercer año. Los números, amplitudes y longitudes medias de estos peces en su segundo y tercer año se dan en la Tabla 20, por mes para cada año y para todos los años combinados.

Las longitudes medias mensuales para todos los años combinados (círculos rellenos) y para cada uno de los años (círculos abiertos) y las amplitudes de longitud para todos los años combinados han sido graficadas en la Figura 45 para dar una estimación de la tasa de crecimiento. El crecimiento es más rápido de marzo a septiembre durante el primer año de vida; al final de su primer año estos peces alcanzan una longitud de más o menos 118 mm.; un año más tarde llegan a unos 141 milímetros

Alrededor del 90 por ciento de la anchoveta muestreada en la zona Ecuador-Perú se encontraba en su primer año (Tabla 6). La proporción de las recolecciones constituídas por peces de un año es ligeramente mayor en esta zona que en cualquiera de las otras áreas.

Madurez sexual y desove

Para el examen de la determinación de la madurez sexual solamente se dispuso de las recolecciones correspondientes a 1951-1952 cogidas en el Golfo de Guayaquil.[1] Debido a la uniformidad en el tamaño de las diversas recolecciones provenientes del área Ecuador-Perú, las recolecciones del Golfo de Guayaquil pueden ser consideradas probablemente representativas en alto grado.

---

[1] Después de terminado el manuscrito pudimos disponer de las recolecciones de 1959-1960 para el examen de la madurez sexual. Los resultados del examen concuerdan con las conclusiones a que se había llegado mediante el empleo del material del Golfo de Guayaquil solamente.

Los números de anchovetas procedentes de este golfo examinadas para determinar su madurez sexual aparecen en la Tabla 21, por meses y años. Todas las recolecciones fueron examinadas. Los peces cogidos solamente en los meses anotados en la Tabla (septiembre a enero) presentaban gónadas perceptibles, excepto los de las muestras de noviembre en las que todos los peces examinados se encontraron inmaturos, salvo una anchoveta hembra desovada. Todas las recolecciones de abril a agosto consistían de anchovetas inmaturas.

No se encontraron hembras maduras en las recolecciones hasta diciembre cuando tres de las 38 hembras examinadas estaban en condiciones muy próximas al desove. En enero, cuatro de las 13 hembras examinadas estaban en un estado similar. También se encontraron en estos dos meses grupos de anchovetas hembras acercándose a la madurez con índice de gónadas en la clase 3-6. También se hallaron hembras en esta clase en las recolecciones de septiembre-octubre. En todas las recolecciones después de septiembre-octubre se encontraron hembras desovadas. Concurrente con este nivel creciente de madurez hubo una disminución en el número de hembras inmaturas (índice de gónadas menos de 3) de 66 en septiembre-octubre a sólo 13 en diciembre y ninguna en enero.

Los tamaños de las anchovetas sexualmente inmaturas examinadas de la recolección de noviembre indicaron que estaban al completar su primer año de vida. Conforme maduraron, este grupo de peces probablemente contribuyó a la población que desovó en diciembre y enero y puede haber contribuído a la continuación del desove hasta los meses de febrero y marzo; la presencia de peces pequeños en los meses de abril y mayo, tanto en 1958 como en 1959, puede reforzar esta opinión.

Sin embargo, los datos indicaron definitivamente un aumento gradual en la madurez de la anchoveta en el Golfo de Guayaquil, culminando en desove en diciembre y enero. El desove en esta área probablemente se extiende más en el año (dentro de febrero y posiblemente marzo) de lo que nuestras recolecciones indican, sobre la base de las anchovetas hembras inmaturas de casi un año de edad en noviembre, de las hembras inmaturas en las poblaciones en el mes de enero, y de los peces pequeños en la población en los meses de abril y mayo.[1]

En todas las recolecciones, solamente se encontraron siete anchovetas hembras con índice de gónadas de 6 o más. Estas hembras sexualmente maduras medían de 117 a 145 mm. de longitud. En consecuencia, los especímenes fueron representativos de ambos grupos de edades: el constituído por peces al completar su primer año y el constituído por peces al completar su segundo año.

---

[1] En la recolección de marzo de 1960 se capturaron peces maduros.

LITERATURE CITED - BIBLIOGRAFIA CITADA

Alverson, F. G. and B. M. Shimada

1957 Eastern Pacific fishery for tuna baitfishes, with particular reference to the anchoveta *(Cetengraulis mysticetus)*. Inter-Amer. Trop. Tuna Comm., Bull., Vol. II, No. 2, pp. 21-61, (English), pp. 62-79 (Spanish).

Berdegué A., J.

1958 Biometric comparison of the anchoveta, *Cetengraulis mysticetus* (Günther), from ten localities of the Eastern Tropical Pacific Ocean. *Ibid.*, Vol. III, No. 1, pp. 3-53 (English), pp. 54-76 (Spanish).

Clark, F. N.

1934 Maturity of the California sardine *(Sardina caerulea)*, determined by ova diameter measurements. Calif. Fish and Game Comm., Fish Bull., No. 42, 49 pp.

Howard, G. V.

1954 A study of populations of the anchoveta, *Cetengraulis mysticetus*, based on meristic characters. Inter-Amer. Trop. Tuna Comm., Bull., Vol. I, No. 1, pp. 1-24. (Spanish summary).

Howard, G. V. and A. Landa

1958 A study of the age, growth, sexual maturity, and spawning of the anchoveta *(Cetengraulis mysticetus)* in the Gulf of Panama. *Ibid.,* Vol. II, No. 9, pp. 391-437 (English), pp. 438-467 (Spanish).

Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 90, No. 3, July, 1961
pp. 336–337

Louver Efficiency in Deflecting Downstream Migrant Steelhead

A louver facility constructed early in 1960 in Maxwell Irrigation Canal, Umatilla River, Oregon, proved very effective in deflecting immature migrating steelhead. The principles of employing louvers to deflect fish were originally studied and demonstrated to be of practical application at the Tracy Pumping Plant near Tracy, California (Bates and Vinsonhaler, 1957; Bates, Logan, and Pesonen, 1960). The Maxwell installation has demonstrated that the principles incorporated in the Tracy structure for deflecting chinook salmon and striped bass in a canal with a total flow capacity of 5,000 c.f.s. are equally applicable for deflecting young steelhead in a canal with a maximum flow capacity of 100 c.f.s.

The installation had the double purpose of serving as an experimental facility and of providing an economical means of diverting steelhead from the irrigation system served. It included both a vertical and a horizontal louver section. Study of the horizontal louver section provided information of value, but since the depth of the canal precluded a satisfactory evaluation of its effectiveness for diverting young steelhead, it is not discussed at length in this report.

THE FACILITY

Figure 1 shows the major features of the louver installation and is largely self-explanatory. Since hydraulic conditions must be provided that insure smooth flow for proper operation of louvers, a concrete-lined canal section was constructed upstream from the existing control gate. This concrete section is 15 feet wide, 5 feet deep, and 50 feet long. The irrigation canal was widened alongside the concrete section by approximately 15 feet to permit diversion of all irrigation flow around the entire structure during periods when modifications were made within the louver structure.

The vertical louver facility was placed on a 20° angle to the direction of flow. The length of the louver line was 30 feet and the height 5 feet. Slope of the horizontal louver facility to the canal floor was approximately 15°. Along the line of louvers and starting at the canal floor, the louver slats were installed with 1-inch clear spacing for the first 9 feet and at 0.5-inch clearance for the remaining, or uppermost, 3 feet of the downstream end. For both facilities, fish passing into the bypass system were carried by separate conduit through the left bank canal wall

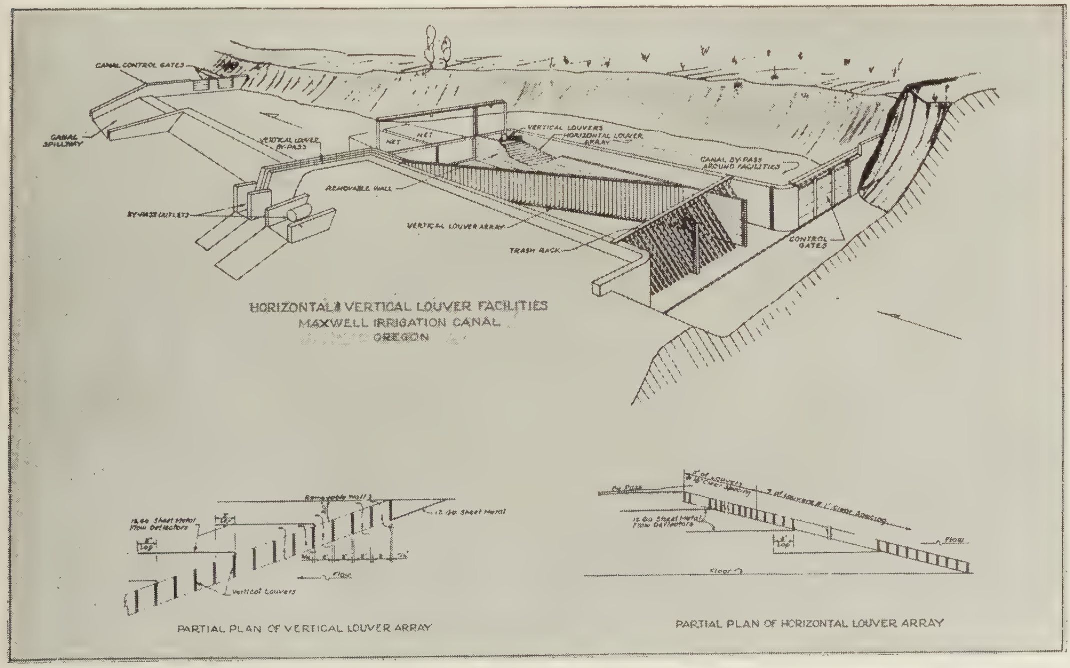

CANAL CONTROL GATES
CANAL SPILLWAY
VERTICAL LOUVER BY-PASS
NET
NET
VERTICAL LOUVERS
HORIZONTAL LOUVER ARRAY
CANAL BY-PASS AROUND FACILITIES
REMOVABLE WALL
BY-PASS OUTLETS
VERTICAL LOUVER ARRAY
TRASH RACK
CONTROL GATES
HORIZONTAL & VERTICAL LOUVER FACILITIES
MAXWELL IRRIGATION CANAL
OREGON
Removable wall
12 Ga. Sheet Metal
12 Ga. Sheet Metal Flow Deflectors
Lap
Lap
Flow
Vertical Louvers
PARTIAL PLAN OF VERTICAL LOUVER ARRAY
By-Pass
12 Ga. Sheet Metal Flow Deflectors
Lap
Flow
Floor
PARTIAL PLAN OF HORIZONTAL LOUVER ARRAY

Figure 1.—Horizontal and vertical louver facilities, Maxwell Irrigation Canal, Oregon.

TABLE 1.—*Influence of louver slat spacing and of approach velocity on efficiency of vertical louvers in deflecting young steelhead*[1]

Approach velocity (feet per second)	Spacing (inches)	Fish through bypass (number)	Fish through louvers (number)	Efficiency (percent)
1.3	2	402	8	98.0
1.7	2	596	12	98.0
2.6	2	1,122	16	98.6
3.6	2	508	8	98.4
1.9	4.25	44	2	95.6
2.4	4.25	642	28	95.8
2.6	4.25	2,265	232	90.7
3.6	10	188	113	62.6

[1] Louver line placed on a 20° angle to flow; mean fork length of fish 7.6 inches.

to an inclined screen fish trap attached to the discharge end of each bypass.

To determine the numbers of fish which might pass through the louvers during any test period, nets were installed at the downstream end of each of the two canals. The nets were hung on steel frames which in turn were held in position by guide slots. Hoists for lowering and raising the nets were operated manually.

RESULTS

To eliminate any question that the nets captured all fish which passed through the louver array, electrical fish-shocking equipment was utilized. At the conclusion of each test the entire area immediately downstream from the louvers and into the net entrances was shocked. After employing this technique for a 2-week period and finding no fish, shocking was terminated.

Table 1 summarizes the results of a series of tests to determine the efficiency of the vertical louver installation under several operating conditions. While slat spacing of 2 inches proved most efficient, very good results were also obtained with a 4.25-inch spacing. Even with 10-inch spacing, over 60 percent of the young steelhead approaching the array were deflected. No significant difference in efficiency was found within the range of approach velocities tested.

While it is evident that a louver installation is feasible for immature, migrating steelhead and for the physical conditions that exist at Maxwell Canal, there are two major limitations that should be noted when results obtained with the two types of louver installations tested are judged. Debris handicapped netting operations so that the duration of fishing time was not constant in all of the tests. The abundance of downstream migrant steelhead varied greatly and at times was so low that tests could not be conducted.

CONCLUSIONS

On the basis of one season's operation of the louver installation at Maxwell Canal, the following conclusions appear warranted: (1) application of louver principles for deflecting downstream migrant steelhead proved successful; (2) a vertical louver installation was very effective in deflecting downstream migrant steelhead; and (3) physical conditions precluded an adequate trial of the efficiency of a horizontal louver installation.

LITERATURE CITED

BATES, DANIEL W., AND RUSSELL VINSONHALER. 1957. Use of louvers for guiding fish. Trans. Am. Fish. Soc., 86: 38–57.

BATES, DANIEL W., ORREN LOGAN, AND EVERETT A. PESONEN. 1960. Efficiency evaluation, Tracy fish collecting facility. Bureau of Reclamation, Sacramento, California, 70 pp.

DANIEL W. BATES
STANLEY G. JEWETT, JR.

U. S. Bureau of Commercial Fisheries
Columbia Fisheries Program Office
Portland, Oregon

Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 90, No. 2, April, 1961
pp. 153–159

Environmental Changes in Lake Erie[1]

6

Alfred M. Beeton
U. S. Bureau of Commercial Fisheries, Biological Laboratory
Ann Arbor, Michigan

ABSTRACT

Comparison of data compiled during the past 60 years with those from recent studies shows that major changes have occurred in the bottom and fish faunas of Lake Erie. The bottom fauna was formerly dominated by the nymphs of *Hexagenia*, but at present midge larvae and oligochaetes are most abundant. Blue pike (*Stizostedion vitreum glaucum*) and cisco (*Coregonus artedii*), which formerly dominated the commercial catch, are scarce, while other species are more plentiful than formerly. The concentrations of various major ions have increased as much as 10 p.p.m. The mean annual water temperatures are approximately 2° F. warmer today than during the 1918–28 period. Low levels of dissolved oxygen have been observed several times since 1930, and recently very low concentrations were found in the bottom waters covering many square miles of the central basin. Although similar conditions may have existed in the past, it appears that greater areas are involved at the present.

INTRODUCTION

It has been stated that Lake Erie has changed during the past 60 to 100 years and that these changes may be due to rising introductions of sewage and other materials from an increased human population (Powers, Jones, Mundinger, and Ayers, 1959). It has also been suggested that the lake is undergoing accelerated eutrophication (Beeton, 1960). Heretofore no attempt has been made, however, to make a detailed examination of the available data that might show such changes in the lake.

A marked change in Lake Erie would offer a unique situation since eutrophication has not been demonstrated in a lake of this size. Studies have been made of the eutrophication of a number of lakes (Hasler, 1947). Probably the best documented is that of the Zurichsee, Switzerland, where the deeper basin, Untersee, changed in a relatively short time from an oligotrophic to a eutrophic condition (Minder, 1926). Evidence of eutrophication of Lake Washington has recently been published (Edmondson, Anderson, and Peterson, 1956).

Lake Erie is the shallowest of the five Great Lakes, with a mean depth of 63.9 feet (Wright, 1955). It is naturally divided into three commonly recognized sections by two prominent peninsulas, Point Pelee and Long Point (Figure 1). The eastern basin, east of a line connecting Erie, Pennsylvania, and the tip of Long Point, is the deepest portion of the lake (maximum depth, 210 feet). The central basin, between Long Point and Point Pelee, makes up the greater portion of the lake. It has a very uniform bottom, and most of its area is between depths of 60 and 78 feet. The area west of a line connecting Sandusky, Ohio, and Point Pelee is the shallow western basin (maximum depth, 54 feet).

Several studies have been made of Lake Erie during the past 60 years. The U. S. Geological Survey made chemical analyses of Great Lakes waters in 1906–07 (Dole, 1909). A survey was made of coliform bacteria in Lake Erie in 1913 (International Joint Commission, 1914). Many of these sampling stations were revisited in 1946–48 (International Joint Commission, 1951). The Bureau of Fisheries took part in two co-operative surveys: western basin, 1928–30 (Wright, 1955), and central and eastern basins, 1928–29 (Fish, 1960). Chandler (1940, 1942a, 1942b, 1944) and Chandler and Weeks (1945) made extensive collections of plankton and physical–chemical data in the Bass Island region, 1938–42. The Fisheries Research Laboratory, University of Western Ontario, conducted limnological investigations in the central basin, 1947–53 (Powers *et al.*, 1959). The Bureau of Commercial Fisheries has been collecting extensive limnological information since 1957. These studies of open-lake conditions can be supplemented by water-quality data collected at various water-treatment plants. It has been demonstrated that the intakes of several of these plants (Lorain, Ohio; Cleveland, Ohio; Erie, Pennsylvania; and Woodlawn, New York) are situated so that open-lake water is taken in rather than littoral waters which are frequently influenced by local river discharge. Consequently, data

---

[1] Presented at the meeting of the Lake Erie Fish Management Committee, Niagara Falls, Ontario, May 11, 1960.

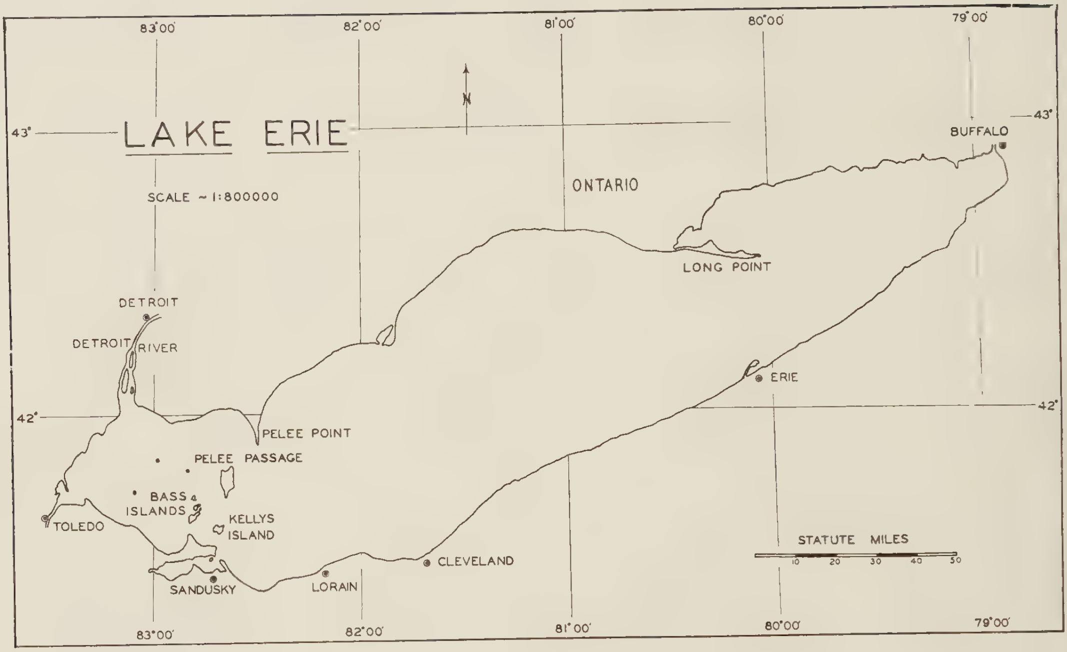


FIGURE 1.—Lake Erie.

from these sources represent open-lake conditions (Powers *et al.*, 1959).

BIOLOGICAL DATA

The present study does not concern itself with changes in the fish population, although some of these changes are no doubt related to progressive modifications of the environment. Shifts involving regularly exploited species, such as the collapse of the cisco (*Coregonus artedii*) fishery in the middle 1920's, the long-term upward trend of the walleye (*Stizostedion vitreum vitreum*) from the early 1930's to the middle 1950's, and the recent near-disappearance of blue pike (*Stizostedion vitreum glaucum*) and sauger (*Stizostedion canadense*), have been well documented in published statistics and some have been discussed in special articles. We have only limited knowledge, however, of the extent of increase of such little-utilized species as gizzard shad (*Dorosoma cepedianum*) and alewife (*Alosa pseudoharengus*) or of the American smelt (*Osmerus mordax*), which is exploited commercially in Canada only.

Bottom fauna

Evidence is convincing that major changes have occurred in the bottom fauna. Prior to 1953 the population of mayfly larvae (*Hexagenia*) in the island region was around 400 per square meter of lake bottom (Britt, 1955a). A prolonged period of calm weather in the summer of 1953 resulted in thermal stratification that was accompanied by severe oxygen depletion in the bottom waters. A week later Britt (1955a) found only 44 live mayfly larvae per square meter. The mayflies recovered rapidly in 1954 (Britt, 1955b), but in 1957 we found only 39 nymphs per square meter.

Preliminary analysis of our data from a number of stations around the islands shows that oligochaetes increased from 12 per square meter in 1929 (Wright, 1955) to 551 per square meter in 1957 and midge larvae from 56 per square meter in 1929 to 299 per square meter in 1957. Caddisfly larvae were formerly abundant but averaged less than 1 per square meter in 1957. The nature of the changes is well illustrated in the comparison of data collected by the same methods in similar sediments and depths from stations near South Bass Island in 1929–30 and 1958 (Table 1). Similar changes were observed in Maumee Bay by Brown (1953) when he compared his 1951 data with those published by Wright (1955).

TABLE 1.—*Number of bottom organisms per square meter in the vicinity of South Bass Island in 1929–30 (Wright, 1955) and in 1958*

Item	1929 Station 158	1930 Station 158	1958 Station 2	1958 Station 3
Number of samples	20	16	40	7
Hirudinea	6	4	37	27
Oligochaetes	6	3	559	635
Hexagenia	312	515	49	44
Tendipedidae	81	22	257	280
Gastropods	12	24	7	0
Fingernail clams	16	8	55	37
Trichoptera	20	1	3	0

Limited data from the area 4 miles east of Kelley's Island, which may be representative of the central basin for 1929, 1930, 1957, and 1959, show that the large larvae of the midge, *Tendipes tendipes plumosus*, have replaced mayfly nymphs as the dominant larger organism. Oligochaetes and fingernail clams showed an increase over the 1929–30 samples. Comparison of the 1957 samples with those taken after a period of very low oxygen values in the central basin in 1959 showed that numbers of all organisms except nematodes had decreased.

Bacteria

The bacterial load at the outlet of the Detroit River increased threefold between 1913 and 1946–48 (International Joint Commission, 1951). Similar increases were found in the entire western basin. In 1913 the average concentration of coliform bacteria was 175.2 per 100 milliliters; in 1946–48 it was 443.9 per 100 milliliters.[2] This increased bacterial load is related to a population growth in the area from about 1,000,000 in 1910 to 3,500,000 in 1948. The counts did not change significantly between 1913 and 1946–48 in eastern Lake Erie: ". . . the bacterial pollution of the main body of eastern Lake Erie is the same as in 1913" (International Joint Commission, 1951, p. 290).

Plankton

Information on the plankton is insufficient for a valid comparison of earlier and more recent years. Furthermore, the studies that have been made show great seasonal fluctuations and considerable year-to-year differences in abundance. The statement made by Chandler and Weeks (1945) that, "Until a greater knowledge of the extent of the annual variations is acquired any attempt to generalize on the basis of observations limited to one season or even a complete year will have little meaning," is still valid, especially since the plankton of Lake Erie has received little attention in the last 15 years. Chandler (1942b) found that the composition and abundance of plankton in the island region in 1939 was closely similar to that of 1929–30 (Wright and Tidd, 1933). Despite sharp differences between Chandler's 1939 and 1940 samples, the relative importance of diatoms and green and blue-green algae was approximately the same in 1929–30 and 1939–40.

PHYSICAL AND CHEMICAL DATA

Temperature

Water temperature records from the Chestnut Street filtration plant at Erie, Pennsylvania, show a definite increase in mean annual values for the 1918–58 period (Erie, Pennsylvania, Bureau of Water, 1958). The moving means of these temperatures indicate that the lake is between 1.5° and 2.0° F. warmer than during the 1918–27 period (Figure 2). Moving means were calculated by using the first 10 years as a base (1918–1927); then the eleventh year was added and the first year subtracted to obtain a new average and the process continued through 1958. The moving means are credited to the final year in each decade. A comparison of the moving means of water temperature with 10-year moving means of annual air temperature in southwestern Ontario (Thomas, 1957) shows, as would be expected, that the warming trend of the lake follows that of the climate. The greatest increase in mean annual water temperatures occurred between 1925 and 1930. There has not been a significant change in the trend in the temperature since this warming period.

Transparency

The usual decrease of transparency in a lake undergoing eutrophication has not occurred in Lake Erie. Most of the Secchi-disc readings in the summer of 1929–30 were 1 to 2 meters in the western basin (Wright, 1955). The average disc depth in the summer was

---

[2] Average for 1913 based on data from stations 178–209 and 274–285 (International Joint Commission, 1914). The 1946–48 average is based on data in Table 22, sampling ranges B-H-R-C, A-G, G-N, W-G, W-F, G-F, T-N, R-F, C-K-E, F-E, E-M, and M-T (International Joint Commission, 1951). The 1913 results, expressed in terms of the Phelps Index, were multiplied by 2.4, as suggested by the International Joint Commission (page 70, 1951), to make comparisons between the two investigations.

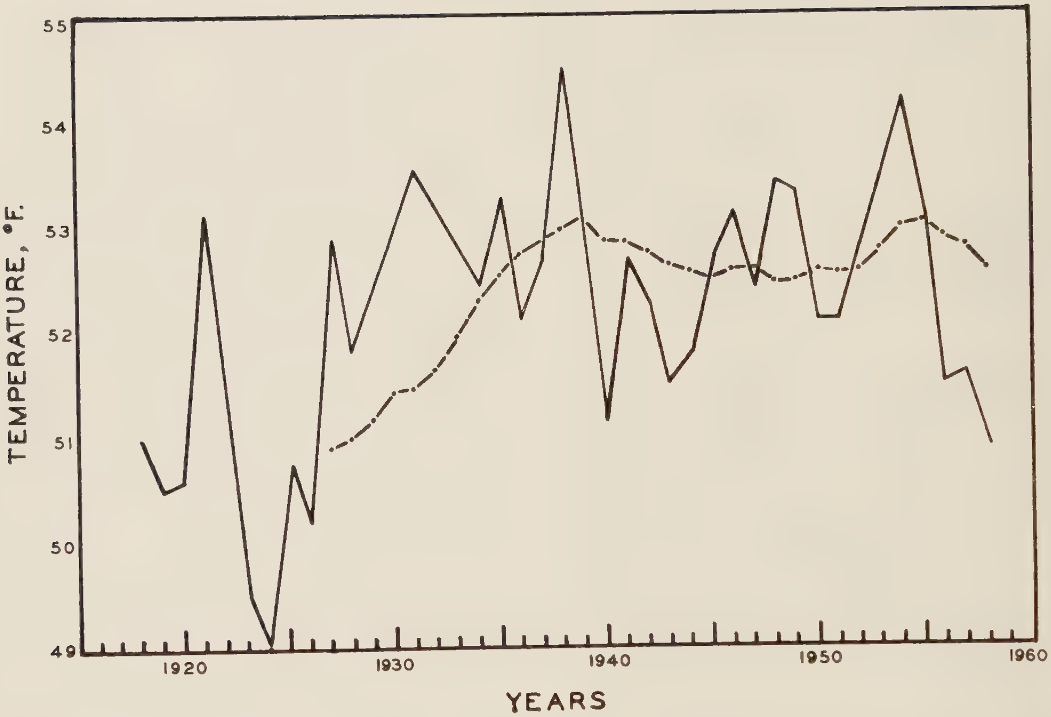


FIGURE 2.—Water temperatures at Chestnut Street filtration plant, Erie, Pennsylvania, 1918–58. Solid line, annual temperature; broken line, 10-year moving means of annual temperature.

1.1 meters in 1939, 1.1 meters in 1940, and 1.7 meters in 1941 (Chandler, 1940, 1942a, 1944). Our average disc depth in the summer of 1958 was 1.5 meters. Similar comparisons can be made for the central basin. The average disc depth in 1929 (Fish, 1960) was 4.0 meters; our average disc reading was 3.3 meters in 1958. Transparency measurements made by the University of Western Ontario (Powers *et al.*, 1959) were all appreciably greater than those recorded elsewhere. Average Secchi-disc depths ranged from 6.4 meters in 1947 to 9.8 meters in 1949 at their station 2. This greater transparency along the north shore of the central basin probably is due to the clearer waters originating from the Detroit River. Our drift-bottle studies of 1958 indicate that the main flow of Detroit River water is through Pelee Passage and along the north shore.

Major ions

The concentrations of most major ions have increased since 1906–07 (Dole, 1909). The recent analyses show increases of from 1 to 10 p.p.m. in calcium, magnesium, sodium plus potassium, and sulfates over the earlier values (Table 2). Total solids increased from 133 to 183 p.p.m. Some earlier determinations of total solids in 1901–03 off Erie, Pennsylvania, averaged 143.5 p.p.m. (Lewis, 1906). Chlorides, recorded by a number of agencies, show a consistent increase. An average of Wright's (1955) data for the island region in 1930 was 10.3 p.p.m. The International Joint Commission average for the western basin

TABLE 2.—*Average concentrations (p.p.m.) of the major ions and total solids in Lake Erie water*

Item	1906–07[1]	1934–38[2]	1948–49[3]	1957[4]	1958[5]	1958[6]
Calcium	31.0	38.1	35.7	40.0	36.0	36.7
Magnesium	7.6	8.9	8.6	–	8.9	10.2
Sodium and potassium	6.5	7.7	9.7	9.9	8.7	9.4
Silica	5.9	6.0	2.0	0.9	1.5	1.6
Sulfates	13.0	22.1	22.5	20.5	23.0	20.7
Chlorides	8.7	14.8	18.2	–	26.0	20.0
Total solids	133.0	164.9	168.0	–	183.0	–

[1] Dole (1909), average of monthly determinations September 19, 1906, to August 28, 1907, Buffalo, N. Y., water intake.

[2] Leverin (1947), average of six determinations between August 20, 1934, and December 21, 1938, Fort Erie, Ont., water intake.

[3] Thomas (1954), average of monthly determinations February 16, 1948, to February 7, 1949, Chippawa, Ont., water intake on Niagara River.

[4] Bureau of Commercial Fisheries data, central basin.

[5] Erie, Pennsylvania, Bureau of Water, 1958.

[6] Bureau of Commercial Fisheries data, western basin.

was 18.7 p.p.m. in 1946–48.[3] Our analyses averaged 20.0 p.p.m. in 1958. The increase has been greater in the central and eastern basins. Chlorides averaged 6.4 in 1901–03 (Lewis, 1906), 8.7 in 1906–07 (Dole, 1909), and 11.9 p.p.m. in 1929 (Fish, 1960). They had increased to 22.2 p.p.m. by 1946–48[4] and ranged from 20 to 26 p.p.m. in 1956–58 (Erie, Pennsylvania, Bureau of Water, 1956, 1957, 1958). The average concentration was 26.3 p.p.m. at the Buffalo, New York, water intake in 1958 (Public Health Service, 1958).

The concentrations of several ions show definite increases during the 30-year period between 1906–07 and 1934–38 (Table 2). These increases may be related to an increasing population. It was during this period that major population growth occurred in the Lake Erie region. Concentrations of total solids have increased steadily at an average rate of about 1 p.p.m. per year. The decreases in silica probably are due, in part, to different analytical methods, although an increased supply of nutrients may have resulted in greater diatom populations and subsequent decreases in silica.

Data presented by Powers *et al.*, (1959, Table 10) indicate appreciably greater increases in several of the ions. They compared the chemistry of the Detroit River for 1854, 1882, and 1897 (Lane, 1899), however, with determinations made at various water intakes on Lake Erie. Such a comparison is questionable, since the chemistry of the river is somewhat different from that of the lake (Tables 2 and 3). Furthermore, most of the change in concentrations of various ions noted in the lake is not found in the river water. Concentrations of sodium-plus-potassium and chlorides at the head of the Detroit River are the same today as in the past. Total solids, calcium, and sulfates have increased and silica has decreased (Table 3). Undoubtedly, considerable amounts of various ions are added to the waters of the river at and below Detroit. Sufficient information on the chemistry of this section of the river to make valid comparisons, however, is not available.

TABLE 3.—*Concentrations (p.p.m.) of the major ions and total solids in the Detroit River*

Item	1854[1]	1882[1]	1897[1]	1934–38[2]	1946–48[3]	1948–49[4]	1957[5]
Calcium	20.0	24.8	24.8	27.5	–	28.0	30.7
Magnesium	–	7.4	6.1	8.0	–	8.0	–
Sodium and potassium	3.7	–	–	3.0	–	4.8	3.4
Silica	5.0	8.9	6.0	7.3	–	3.8	2.6
Sulfates	6.6	6.7	7.8	12.9	–	17.4	–
Chlorides	–	7.5	–	5.6	7.3	6.5	–
Total solids	98.1	117.1	114.4	118.6	141.0	131.0	–

[1] Lane (1899), City of Detroit water intake.

[2] Leverin (1947), average of five determinations between July 31, 1934, and March 23, 1938, Windsor, Ont., water intake.

[3] International Joint Commission (1951), average of determinations made on transects from Windmill Point to Canadian shore at head of Detroit River (Table 21).

[4] Thomas (1954), average of monthly determinations February 18, 1948, to January 14, 1949, Windsor, Ont., water intake.

[5] Average concentrations in samples taken at 5-mile intervals from mouth to head of Detroit River, November 17, 1957, Bureau of Commercial Fisheries.

Dissolved oxygen

Very low dissolved-oxygen concentrations have been observed in recent years, but low concentrations also occurred previously. The severity of oxygen depletion may, nevertheless, be somewhat greater at present than in the past. Because there is vertical turbulence in the shallow western basin, dissolved oxygen is usually around 80-percent saturation near the bottom, except during periods of thermal stratification such as occurred in 1953 (Britt, 1955a). Averages of the percentage saturation for bottom waters in 1928, 1929, and 1930 (Wright, 1955) are 83.5, 90.7, and 87.2. The average dissolved oxygen near the bottom in 1939 was 7.4 p.p.m., and at an average temperature of 19.8° C., the percentage saturation was 80.[5] Our average percentage saturation was 80 in 1958.

If dissolved-oxygen concentrations alone are considered, conditions in the eastern basin appear to be much the same 30 years ago as they are today. The percentage saturation in the bottom waters averaged 60 to 70 in 1928 and 1929 (Fish, 1960), in 1950–51 (Powers *et al.*, 1959), and in 1957 (Bureau of Commercial Fisheries). Some very low dissolved-oxygen concentrations have been observed in the bottom waters of the central basin. The most recent and perhaps the severest oxygen deficit occurred in 1959 when oxygen could not be detected over extensive areas covering many square miles. We found an area with only 10-percent saturation in August 1958. Calculations of percentage saturations from data of Powers *et al.* (1959) for 1948, 1949, and 1950 give three low values of 35, 22, and

---

[3] See footnote 2.

[4] Average of results for sampling ranges P-1W and LC, Table N-17 (International Joint Commission, 1951).

[5] Calculations based on data presented by Chandler (1940) for May 9 through September; the 1928–30 observations covered a similar period.

35. Fish (1960) recorded two observations of 44- and 52-percent saturation in 1929. A low of 8.6-percent saturation was observed in 1930 at the western limits of the central basin (Wright, 1955). There is little information, however, on the extent both in time and area of these low concentrations. The recent occurrences of low oxygen concentrations may not, therefore, be indicative of a great change in the central basin. Average percentage saturation for comparable periods does, nevertheless, seem to be lower now than in 1929. The average percentage saturation in 1929 was 83.3; it was 67.4 during 1948–52 and 63.3 in 1958.[6]

Biochemical oxygen demand

The average biochemical oxygen demand (B.O.D.) has not changed appreciably since 1946–48 in the east end of the lake. It was 0.97 in the open lake in 1946–48 (International Joint Commission, 1951[7]) and 0.88 at the Buffalo, New York, water intake in 1957–58 (Public Health Service, 1958).

Nitrogen and phosphorus

Information is limited on the concentrations of nitrogen and phosphorus in Lake Erie. Such data as do exist are frequently questionable and difficult to interpret. Data compiled on nitrogen from the western basin seem, however, to be reliable and to show a trend. The average free ammonia in the island area increased from 0.013 p.p.m. in 1930 (Wright, 1955) to 0.036 p.p.m. in 1942 (Chandler and Weeks, 1945). An average of the International Joint Commission's records was 0.033 p.p.m. in 1946–48. Our 1958 average was 0.092 p.p.m. Nitrites increased from 0.005 p.p.m. in 1930 (Wright, 1955) to 0.008 p.p.m. in 1942 in the island area (Chandler and Weeks, 1945). Nitrates increased from 0.10 p.p.m. in 1930 (Wright, 1955) to 0.225 in 1942 (Chandler and Weeks, 1945). Our average total nitrogen for 1958 from stations around the islands was 0.83 p.p.m.; Chandler and Weeks (1945) recorded an average of 0.265 in 1942.

Data on nitrogen in the central and eastern basins show marked discrepancies. Determinations of free ammonia for 1901–03 (Lewis, 1906, 0.046 p.p.m.), 1925 (U. S. Corps of Engineers, personal communication, 0.05 p.p.m.), and for Erie, Pennsylvania, for 1956–58 (0.030 to 0.045 p.p.m.) indicate no change. Albuminoid ammonia decreased from 0.106 p.p.m. (Lewis, 1906) and 0.125 p.p.m. (U. S. Corps of Engineers) to 0.042 p.p.m. and 0.05 p.p.m. in 1956 and 1958. Nitrates increased from 0.085 p.p.m. in 1901–03 to 0.40 p.p.m. and 0.30 p.p.m. in 1956 and 1958. The average for free ammonia in 1928 (Fish, 1960) was 0.02 p.p.m., well below the figure of 0.045 p.p.m. at Erie, Pennsylvania, in 1958. Determinations for free and albuminoid ammonia, nitrites, and nitrates made at the Cleveland water intake in 1910 and 1911 by Jackson (Wright, 1955) were essentially the same as those made in 1956–58 at Erie, Pennsylvania.

Phosphorus concentrations apparently increased. The magnitude of this increase is difficult to ascertain, since few determinations have been made for phosphorus and some doubt exists as to the exact unit in which data were recorded. The average total phosphorus in the island region in 1942 was 14.4 parts per billion (Chandler and Weeks, 1945). Average total phosphorus for this region found in the present study was 33 parts per billion in 1958 and 36 parts per billion in 1959. The average soluble phosphate-P content was 3.0 parts per billion during the last half of 1942 (Chandler and Weeks, 1945). An average of Curl's (1959) data for a comparable period in 1950 was 4.7 parts per billion.[8]

CONCLUSIONS

The bottom fauna and the fish fauna of Lake Erie have changed substantially and increases have taken place in temperature, in coliform bacteria, and in the concentrations of certain ions. Data on transparency, plankton, and dissolved oxygen, however, give no conclusive evidence of changes in Lake Erie. It is certainly doubtful whether the 1- to 10-p.p.m. increase in the concentrations of the major ions is of any consequence to the biota. The seeming increases in the concentrations of nitrogen and phosphorus compounds, on the contrary, could be very important biologically and deserve further study. The type of change in the bottom fauna indicates an increase in the organic component of the sediments.

Any great changes in the chemistry or plankton of the lake must originate in changes in the characteristics of the waters flowing into the lake, especially in the western basin where the great flow of the Detroit River leads to an estimated flushing rate of about 2 months. Information is needed on the chemical characteristics, past and present, of the Detroit River and other streams that flow into Lake Erie.

---

[6] Percentage saturation for 1948–52 calculated from University of Western Ontario data from station 2 (Powers *et al.*, 1959). The 1958 figure is based on data collected by the Bureau of Commercial Fisheries every 3 weeks at two stations northwest of Lorain, Ohio.

[7] See footnote 4.

[8] Based on data plotted in his Figure 4 for July–December, 1950.

Our present knowledge of conditions in the lake suggests any trend toward eutrophication of Lake Erie can be detected best in the bottom in the western and central basins. The chemical nature of the sediments influences the overlying water, but the effects may be important only during prolonged thermal stratification. Most of the changes in the bottom fauna seem to be confined to the western and central basins. A fauna similar to that of the upper Great Lakes exists in the region of Long Point.

LITERATURE CITED

BEETON, ALFRED M. 1960. Great Lakes limnological investigations. Proc. Third Conf. Great Lakes Res., Present status and future needs; Mich. Inst. Sci. Tech., Great Lakes Res. Div., Publ. No. 4, pp. 123–128.

BRITT, N. WILSON. 1955a. Stratification in western Lake Erie in summer of 1953; effects on the *Hexagenia* (Ephemeroptera) population. Ecology, 36: 239–244.

———. 1955b. *Hexagenia* (Ephemeroptera) population recovery in western Lake Erie following the 1953 catastrophe. Ecology, 36: 520–522.

BROWN, EDWARD H., JR. 1953. Survey of the bottom fauna at the mouths of ten Lake Erie, south shore rivers. Lake Erie Pollution Survey, Ohio Dept. Nat. Res., Div. Water, Final Rept. 201 pp.

CHANDLER, DAVID C. 1940. Limnological studies of western Lake Erie. I. Plankton and certain physical–chemical data of the Bass Island region, from September, 1938, to November, 1939. Ohio Jour. Sci., 40: 291–336.

———. 1942a. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecology, 23:41–52.

———. 1942b. Limnological studies of western Lake Erie. III. Phytoplankton and physical–chemical data from November, 1939, to November, 1940. Ohio Jour. Sci., 42: 24–44.

———. 1944. Limnological studies of western Lake Erie. IV. Relationship of limnological and climatic factors to the phytoplankton of 1941. Trans. Am. Micro. Soc., 43: 203–236.

CHANDLER, DAVID C., AND OWEN B. WEEKS. 1945. Limnological studies of western Lake Erie. V. Relation of limnological and meteorological conditions to the production of phytoplankton in 1942. Ecol. Monogr., 15: 435–456.

CURL, HERBERT, JR. 1959. The origin and distribution of phosphorus in western Lake Erie. Limnol. and Oceanogr., 4: 66–76.

DOLE, RICHARD B. 1909. The quality of surface waters in the United States. Part I. Analyses of waters east of the one hundredth meridian. U. S. Geol. Sur., Water Supply Paper 236, 123 pp.

EDMONDSON, W. T., G. C. ANDERSON, AND DONALD R. PETERSON. 1956. Artificial eutrophication of Lake Washington. Limnol. and Oceanogr., 1: 47–53.

ERIE, PENNSYLVANIA, BUREAU OF WATER. 1956. Ninetieth annual report, 1956, 63 pp.

———. 1957. Ninety-first annual report, 1957, 63 pp.

———. 1958. Ninety-second annual report, 1958, 56 pp., insert.

FISH, CHARLES J. 1960. Limnological survey of eastern and central Lake Erie, 1928–29. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. 334, 198 pp.

HASLER, ARTHUR D. 1947. Eutrophication of lakes by domestic drainage. Ecology, 28:383–395.

INTERNATIONAL JOINT COMMISSION. 1914. Progress report of the International Joint Commission on the reference by the United States and Canada in re the pollution of boundary waters, dated January 16, 1914. Govt. Printing Office, 1918, 388 pp.

———. 1951. Report of the International Joint Commission United States and Canada on the pollution of boundary waters. Washington and Ottawa, 1951, 312 pp.

LANE, ALFRED CHURCH. 1899. Lower Michigan waters: a study into the connection between their chemical composition and mode of occurrence. U. S. Geol. Surv., Water-supply Irrigation, Pap. 31. 97 pp.

LEVERIN, HARALD A. 1947. Industrial waters of Canada. Report on investigations, 1934 to 1943. Canadian Dept. Mines Res., Mines Geol. Br., Rept. No. 819, 109 pp.

LEWIS, SAMUEL JAMES. 1906. Quality of water in the upper Ohio River basin and at Erie, Pa. U. S. Geol. Surv., Water-supply Irrigation Pap. 161. 114 pp.

MINDER, LEO. 1926. Biologische–chemische Untersuchungen in Zürichsee. Rev. d'Hydrologie, 3: 1–69.

POWERS, CHARLES F., DAVID L. JONES, PAUL C. MUNDINGER, AND JOHN C. AYERS. 1959. Exploration of collateral data potentially applicable to Great Lakes hydrography and fisheries. Final Rept., Phase II. U. S. Fish and Wildlife Serv., Contract No. 14-19-008-9381. Great Lakes Res. Inst., Univ. Mich., 164 pp.

PUBLIC HEALTH SERVICE. 1958. National water quality network. Annual compilation of data October 1, 1957—September 30, 1958. Public Health Ser. Publ. No. 663. Washington, D. C. 239 pp.

THOMAS, J. F. J. 1954. Industrial water resources of Canada. Upper St. Lawrence River–Central Great Lakes drainage basin in Canada. Dept. Mines Tech. Serv., Water Surv. Rept. No. 3, Mines Br. Rept. No. 837, 212 pp.

THOMAS, M. K. 1957. Changes in the climate of Ontario, *in* Changes in the Fauna of Ontario. Univ. Toronto Press. Royal Ontario Museum, Toronto, pp. 59–75.

WRIGHT, STILLMAN. 1955. Limnological survey of western Lake Erie. U. S. Fish and Wildlife Serv., Spec. Sci. Rept., Fish. 139, 341 pp.

WRIGHT, STILLMAN, AND WILBUR TIDD. 1933. Summary of limnological investigations in western Lake Erie in 1929 and 1930. Trans. Am. Fish. Soc., 63: 271–285.

Pubn. No. 7, Great Lakes Res. Div., Inst. Sci. and Tech., The Univ. of Michigan, 1961

THE HYDROGRAPHY OF SAGINAW BAY

Alfred M. Beeton* and Frank F. Hooper†

Abstract

Three synoptic surveys were made of Saginaw Bay, Lake Huron, in June, August, and October of 1956 by the Michigan Conservation Department and the U. S. Bureau of Commercial Fisheries. Water samples, temperatures, and bottom samples were taken at 53 stations. Water analyses were made for calcium, magnesium, potassium, sodium, sulfate, total alkalinity, total phosphorus, and conductivity.

Low ion content Lake Huron water occupied most of the outer bay during each survey. A tongue of this water extended into the inner bay during the surveys, but its position shifted from the middle of the bay in June to the west shore in August, and then to the east shore in October. Saginaw River water, characterized by high ion content, extended along the east shore during the three surveys and occurred also near the west shore in August and October. Only slight differences were noted in the vertical distribution of any ion or conductivity. The percentage of river water in the inner bay decreased from about 30 per cent in June to 10 per cent in October.

These surveys provided the necessary information on the distribution of river water in the bay for making estimates of flushing rates, lakeward transport of river water, and exchange between lake and river water. As in the case of marine estuaries, the river water was used as a tracer; however, the situation was reversed with higher ion content Saginaw River water flowing out and low salinity water entering the bay from lakeward. The situation in some aspects is more complex than in the marine estuary, since very low salt concentrations had to be dealt with. The salt content of the diluting water, *i.e.*, Lake Huron water, as well as that of the bay and river, had to be included in the calculations. In addition to the variability of river flow there was variation in the salt content of the river. Despite these complications, the methods used by Tully (1949), Ketchum (1950), and Ketchum, Redfield, and Ayers (1951) can be used to evaluate the circulation of this freshwater bay.

During the period of peak river discharge it would take 113 days for a one-day accumulation of river water to move through the bay. The flushing time increased as the river discharge decreased in August and October. A flushing time of 186 days was calculated from the annual average river flow and the distribution of river water in the bay as shown by the three surveys.

Lakeward transport, *i.e.*, the rate at which river water moves lakeward through the bay, was greatest in June and decreased with decrease in river discharge. Lakeward transport was not of the same magnitude, however, as the change in river flow. The rate of flow through the bay was affected by river flow, area of the cross section, and inflow of Lake Huron water.

River flow carried with it an increasing amount of entrained lake water as it moved through the bay and out into the lake. Consequently, there was a compensating inflow of Lake Huron water into the bay. The magnitude of this inflow was considerably greater than the river discharge. This relationship is best described by the transport ratio, *i.e.*, the ratio of total volume moving lakeward to river volume. The volume of river and lake water moving lakeward was as much as 100 times greater than the river flow.

REFERENCES

Ketchum, B. H. 1950. Hydrographic factors involved in the dispersion of pollutants introduced into tidal waters. Journ. Boston Soc. Civil Engineers, 37: 209-314.

________, A. C. Redfield and J. C. Ayers. 1951. Hydrography of the New York bight. Papers Phys. Oceanog., 12(1).

Tully, J. P. 1949. Oceanography and prediction of pulp mill pollution in Alberni Inlet. Bull. Fish Res. Bd. Canada, 83: 169 pp.

---

*Biological Laboratory, U.S. Bureau Commercial Fisheries, Ann Arbor, Mich.

†Institute for Fisheries Research, Michigan Dept. of Conservation, Ann Arbor, Mich.

8

Reprinted from COPEIA, 1961, No. 3, pp. 360–362, September 22
Printed in U. S. A.

SYNONYMY OF THE ATLANTIC OCEAN FILEFISH *ALUTERA HEUDELOTII* HOLLARD.—Four species of the genus *Alutera* (Monacanthidae) are known to occur in the Atlantic Ocean: 1) *Alutera monoceros* (Linnaeus 1758) is a world-wide species, occurring in tropical and temperate regions of the Pacific and Indian Oceans and in both the eastern and western Atlantic Ocean. It has a relatively high number of dorsal and anal fin rays (D. 46–50, A. 47–52). 2) *Alutera scripta* (Osbeck 1765) has a world wide distribution similar to that of *A. monoceros,* occurring in both the eastern and western Atlantic Ocean. It also has a relatively high number of dorsal and anal fin rays (D. 43–49, A. 46–52). 3) *Alutera schoepfii* (Walbaum 1792) occurs only in the western Atlantic, from Nova Scotia to Brazil, in the West Indies, and at Bermuda. It has a relatively low number of dorsal and anal fin rays (D. 32–39, A. 35–41). 4) *Alutera heudelotii* Hollard 1855, occurs in both the eastern and western Atlantic, from Massachusetts to Brazil and at Bermuda, and from Angola to Cape Blanco, Spanish Western Sahara. It also has a relatively low number of dorsal and anal finrays (D. 34–41, A. 38–44).

Alutera monoceros and *A. scripta* can be distinguished from the other two species by several characters, including their relatively high numbers of dorsal and anal fin rays, and are not considered further here.

Alutera punctata Cuvier (by Agassiz in Spix 1831, type locality Brazil) is a nominal species that has recently been shown to be a synonym of *A. schoepfii* (type locality New York) by Berry and Vogele (in press, *Fish. Bull. U.S. Fish and Wildl. Serv.*). *A. punctata* has been recorded from the eastern Atlantic (as by Cadenat, 1937, *Revue des Travaux Office peches maritimes, 10(4):530,* fig. 58; and Poll, 1959, *Exped. Oceanogr. Belge Eaux Cotieres Africaines de l'Atlantique Sud, 4(3B):245, fig. 82*), but these records all apparently refer to *A. heudelotii.* We have seen no specimens of *A. schoepfii* (= *A. punctata*) from the eastern Atlantic; and where published descriptions of this form are adequate, they can be attributed to *A. heudelotii.*

The ontogenetic changes in *A. heudelotii* and *A. schoepfii* and the differences between these two species have been described by Berry and Vogele (*op. cit.*). The spines on the body scales are much smaller and more numerous in *A. heudelotii* giving a "velvety" feeling to the touch. The dorsal spine of *A. heudelotii* is shorter and stouter and has larger barbs, especially between 40 and 140 mm S.L. (Standard Length). The eye to dorsal spine distance of *A. heudelotii* is much smaller (4.6 to 6.6% S.L.) on specimens larger than 100 mm S.L.

The synonymy of *Alutera heudelotii* is recorded for the first time as follows:

Aluterus Heudelotii Hollard, 1855, Annales des Sciences Naturelles, *Zoologie, Ser. 4,* 4: 13 (type locality, Senegal; holotype in Museum d'Histoire Naturelle Paris, no. B. 1947).

Monacanthus (*Aluteres*) *fuscus* Fischer, 1885, Jahrb. Hamburg. Wiss. *Anstalten, 2: 75, pl. II, fig. 6* (type locality Cameroon; holotype destroyed, originally in Naturhistorischen Museum in Hamburg, no. 3943).

Aluteres blankerti Metzelaar, 1919, Report on the fishes, collected by Dr. J. Boeke. . ., *Firma Belinfanti, The Hague, p. 295, fig. 64* (type locality, Cape Blanco; types in Zoologisch Museum Amsterdam, no. 102359).

Alutera ventralis Longley, 1935, *Carnegie Inst. Washington Pub., Year-book, 34: 68* (type locality, Tortugas, Florida; types in U.S. National Museum, nos. 109177–8).

The holotype of *A. heudelotii,* 85 mm. S.L., was originally described as having small scale spines that were smooth to the touch and a strong dorsal spine armed with spines (Hollard 1885:113). The illustration of the holotype of *A. fuscus,* estimated to 87.2 mm. S.L., shows a stout and strong-barbed dorsal spine, a characteristic arch in the ventral profile of the body, and a small eye to dorsal spine distance (Fischer, 1885, pl. II, fig. 6). The illustration of the holotype of *A. blankerti,* 123 mm. S.L., shows the pigment pattern characteristic of this size fish (Metzelaar, 1919, fig. 64). The holotype of *A. ventralis,* 78.5 mm S.L., has been examined (by Berry) and has a short, stout, strong-barbed dorsal spine, small and close-set spines on the body scales, and the characteristic arch in the ventral profile. We believe that the above names are all conspecific and represent the specimens of this form that we have examined from the eastern and western Atlantic.

TABLE 2. NUMBERS OF DORSAL, ANAL, AND PECTORAL RAYS OF SPECIMENS OF *Alutera heudelotii* AND ITS SYNONYMS

	Alutera heudelotii Holotype	*Alutera fuscus* Holotype	*Alutera blankerti* Holotype and Paratype	Eastern Atlantic Specimens	Western Atlantic Specimens	*Alutera ventralis* Holotype
Dorsal rays						
34				1		
35				3		
36		1	1	1	1	
37			1	1	10	
38	1				21	
39					22	1
40					3	
41					1	
Anal rays						
38		1	2	1		
39					3	
40				1	15	
41				4	21	
42	1				16	1
43					1	
44					2	
Pectoral rays						
12				1	3	
13	1	1	1	4	40	1
14			1		17	

Selected body proportions of the type specimens and other specimens of comparable size are given in table 1. Numbers of dorsal, anal, and pectoral rays of the type specimens and other specimens are given in table 2. Data on *A. fuscus* were determined from the original description and illustration; Dr. Werner Ladiges has informed us that the holotype has been destroyed. We are grateful to Dr. J. J. Hoedeman for information on the types of *A. blankerti,* to Madame H. Bauchot for information on the holotype of *A. heudelotii,* and to Dr. Leonard P. Schultz for the opportunity to examine the types of *A. ventralis.* Data on the eastern Atlantic specimens were recorded from specimens in the Musee Royal du Congo Belge (prior determination of Poll, *op. cit.,* p. 245–8, as *A. punctatus* and *A. blankerti*). Data

TABLE 1. STANDARD LENGTH IN MILLIMETERS AND BODY PROPORTIONS IN PERCENT OF STANDARD LENGTH OF SPECIMENS OF *Alutera heudelotii* AND ITS SYNONYMS

	Western Atlantic Specimens	*Alutera ventralis* Holotype	Western Atlantic Specimens	*Alutera heudelotii* Holotype	*Alutera fuscus* Holotype	Eastern Atlantic Specimens	Western Atlantic Specimens	*Alutera blankerti* Holotype	Western Atlantic Specimens	*Alutera blankerti* Paratype
Standard Length Range (mm.)	70.5–78.5	78.5	81.0–89.0	85	87.2	98.5	102–125	123	131–147	137
Head Length	32.9–34.6	33.6	30.1–33.7	34.1	33.4	34.0	31.3–31.8	31.7	30.2–32.7	33.6
Snout Length	27.7–27.8	27.8	26.0–28.7	31.7	28.7	29.4	27.2–27.9	26.0	26.2–28.7	30.7
Eye Diameter	8.2– 9.6	8.7	7.3– 8.4	7.4	8.5	8.3	6.4–8.1	6.5	6.3– 7.7	6.9
Eye to Dorsal Spine Distance	5.7– 6.7	5.7	5.7– 6.7	6.2	4.2	5.2	4.6– 6.6	5.7	5.2– 6.1	5.8
Body Depth	36.2–42.9	41.0	36.4–41.0		37.6	43.6	39.8–44.5	42.3	40.0–43.0	49.6

on the western Atlantic specimens were taken from the manuscript of Berry and Vogele and all measurements and counts were made as described in that work.

Six specimens of 31.6 to 324 mm S.L. from the eastern Atlantic (West Africa) were compared with data from 68 specimens of 30.5 to 240 mm S.L. from the western Atlantic (Brazil to Massachusetts and Bermuda). The distinctive pigmentation pattern in adults and larger juveniles of large, round spots and terminally rounded stripes on the head and body was noted in both groups. The proportional changes in body parts with growth, known to occur in the western Atlantic form, were demonstrated by the smaller series from the eastern Atlantic (the angular ventral body profile in smaller specimens, produced by the ventral extension of the posterior end of the pelvic bone, becoming almost flattened in larger specimens; the body depth relative to the standard length first increasing then decreasing with growth; the eye diameter and the eye to first dorsal spine distance decreasing with growth relative to the standard length). The strong barbs on the first dorsal spine and the relatively widely spaced scale spines were present in smaller specimens of both groups. The number of dorsal and anal rays were slightly less in the eastern Atlantic specimens (dorsal 34 to 36, anal 38 to 41) than in the western Atlantic specimens (dorsal 36 to 41, anal 39 to 44). The numbers of pectoral rays were generally similar (eastern Atlantic 12 to 13, western Atlantic 12 to 14). These numbers are respectively 37, 41, and 13 on a specimen recently described by one of us from the eastern tropical Atlantic (Poll, 1959, *Exped. Oceanogr. Belge Eaux Cotieres Africaines de l'Atlantique Sud, 4(3B):248*).

It seems entirely possible that for certain species of fishes having surface or epipelagic larval and juvenile stages, as *Alutera,* these stages could successfully be transported in the currents of the Gulf Stream System from off the United States to off West Africa and could then become a reproductive component of the eastern Atlantic population. The North and South Equatorial Currents might also transport similar stages from West Africa to the Americas. These features of pan-Atlantic species distributions were suggested by Nichols (1939, *Bull. Bingham Oceanogr. Coll. 7(2):5*) and were commented upon by Lachner (1955, *Proc. U.S. Nat. Mus. 105(3356):193*). If this reasoning is later proved untenable and there is actually no reproductive intermingling between the populations of the species of *Alutera* in the eastern and the western Atlantic, we would still maintain that the eastern and western Atlantic populations are specifically identical. Analysis of large series of specimens from both sides of the Atlantic may warrant the recognition of subspecies in the two areas.—FREDERICK H. BERRY, *U.S. Department of the Interior, Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California, and* MAX POLL, *Musee Royal du Congo Belge, Tervuren, Belgium.*

Proceedings of
he United States
National Museum

MITHSONIAN INSTITUTION • WASHINGTON, D.C.

umber 3448 1961 Volume 112, Pages 563–586

9

STARGAZER FISHES FROM THE WESTERN NORTH ATLANTIC (FAMILY URANOSCOPIDAE)

By FREDERICK H. BERRY *and* WILLIAM W. ANDERSON

Proceedings of
the United States
National Museum

SMITHSONIAN INSTITUTION • WASHINGTON, D.C.

Volume 112 1961 Number 3448

STARGAZER FISHES
FROM THE WESTERN NORTH ATLANTIC
(FAMILY URANOSCOPIDAE)

By Frederick H. Berry and William W. Anderson[1]

This review of the fishes of the family Uranoscopidae from the western North Atlantic is a consequence of our efforts to identify large series of various sizes of these fishes that have been taken in recent years by exploratory fishing in this area. It is based on all the uranoscopid specimens from this area in the collections of the U.S. National Museum, selected specimens from other institutions, and specimens at the U.S. Fish and Wildlife Service's Biological Laboratory at Brunswick, Georgia. Many of the specimens at Brunswick will subsequently be transferred to the U.S. National Museum.

Five species of stargazers have been recognized in our study of the family in the western North Atlantic. Illustrations, diagnostic characters, and known ranges are presented for these species. *Astroscopus y-graecum* Cuvier and *Astroscopus guttatus* Abbott are distinguished. *Execestides* Jordan and Thompson is synonymized with *Gnathagnus* Gill, and *E. egregius* Jordan and Thompson is included in the genus *Gnathagnus*. *Gnathagnus laticeps* (Longley and Hildebrand) is synonymized with *Gnathagnus egregius*. *Kathetostoma albigutta cubana* Barbour is distinguished as a species distinct from *Kathetostoma albigutta* Bean. *Uranoscopus occidentalis* Agassiz, described from Brazil, is included on the basis of the type description.

---

[1] United States Fish and Wildlife Service. This paper is Contribution No. 51 of the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

Astroscopus sexspinosus (Steindachner) was described from Argentina and Rio de Janeiro, Brazil, in the western South Atlantic (Steindachner, 1876) as *Uranoscopus* (*Upsulonophorus*) *sexspinosus*. It reportedly differs from *A. y-graecum* and *A. guttatus* in having a blackened border on the soft dorsal fin (Miranda Ribeiro, 1915), but specimens adequate for assessing its true relationship have not been available.

Data on dorsal and anal rays and data on pectoral rays are given in table 1, p. 566. A chart of distribution of *Kathetostoma albigutta*, *K. cubana*, and *Gnathagnus egregius* is shown in figure 1, next page.

Standard length (S.L.) was measured from the middle of the upper jaw (premaxillary symphysis) to the caudal base. Total length (T.L.) was measured from the most anterior part of the lower jaw to end of the caudal fin.

Dorsal and anal fin ray counts were made by counting the total number of rays (or ray bases), except in a minority of specimens that had the terminal soft ray in very close proximity to the next to the last soft ray. Dissection and clearing and staining showed that in certain specimens the terminal dorsal or anal soft ray was branched to its base and the two terminal elements were articulated beneath the body surface; it was therefore considered a branched ray and was counted as a single ray.

Pectoral and pelvic rays were counted on each side of the fish, and are recorded without respect to right or left sides. Bilateral variation may occur in the number of pectoral fin rays, but the side of a fish having the greater number is randomly right or left.

Terminology of the cranial bones follows Gregory (1933, figs. 244–248).

In the synonymies, a comma is used between the binomial and the author's name only in instances of emended or altered specific combinations; no comma is used in instances of original combinations.

The specimens examined are listed for each species by geographical location from north to south along the Atlantic coast of the United States to southern Florida, then northward, westward, and southward around the Gulf of Mexico into the Caribbean Sea. The following abbreviations are used: USNM, U.S. National Museum; CNHM, Chicago Natural History Museum; CM, Charleston Museum; CAS, California Academy of Sciences; UMML, University of Miami Marine

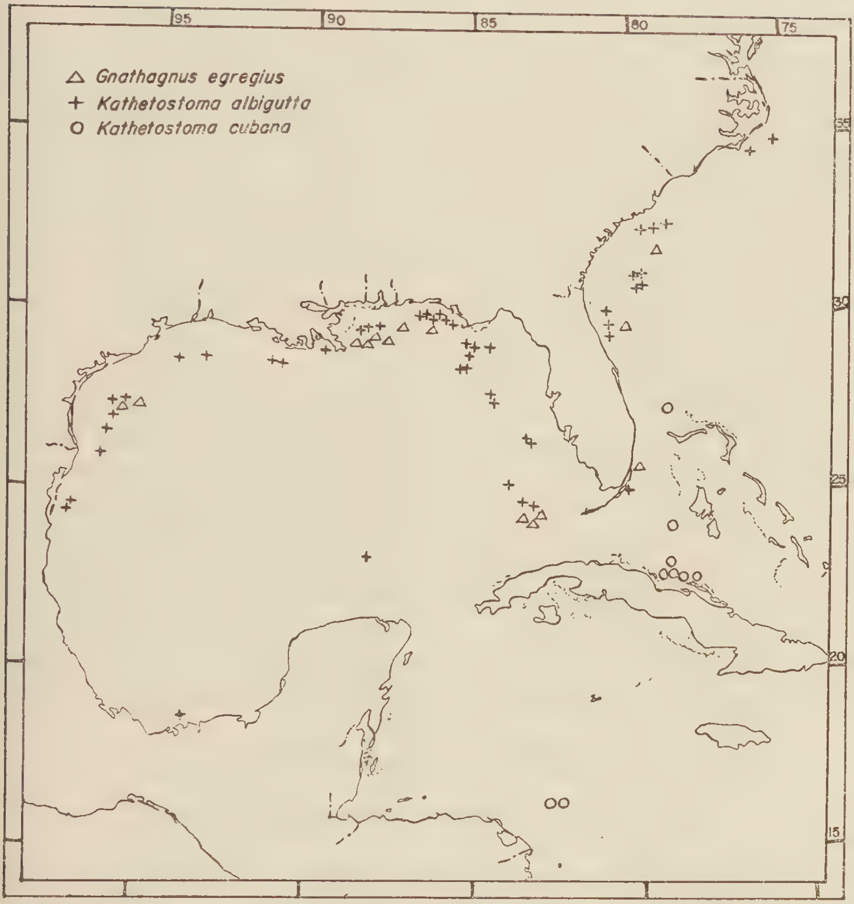


Figure 1.—Distribution of *Kathetostoma albigutta*, *Kathetostoma cubana*, and *Gnathagnus egregius*, including specimens examined and specimens reported by Springer and Bullis (1956, p. 97) and Hildebrand (1954, p. 318). A single specimen of *K. cubana* from east of Puerto Rico is not shown on this chart.

Laboratory; UF, University of Florida; TU, Tulane University; SU, Stanford University; MCZ Museum of Comparative Zoology; UNC, University of North Carolina; CHML, Cape Haze Marine Laboratory; GWM acct. No., G. W. Mead, U.S. Fish and Wildlife Service, Washington, D.C.; BLBG, U.S. Fish and Wildlife Service Biological Laboratory, Brunswick, Ga.

We owe special thanks for assistance in obtaining data on specimens to Leonard P. Schultz and Robert Kanazawa, U.S. National Museum; Myvanwy M. Dick, Museum of Comparative Zoology; G. Palmer, British Museum (Natural History); George S. Myers, Margaret Storey, and Stanley Weitzmann, Stanford University Natural History

TABLE 1.—*Frequencies of dorsal spines, dorsal and anal soft rays, and pectoral rays*

Species	Dorsal spines			Dorsal soft rays				Anal soft rays					
	III	IV	V	12	13	14	15	12	13	14	15	16	17
Astroscopus y-graecum	1	25	2	—	1	14	13	1	11	16	—	—	—
Astroscopus guttatus	—	4	6	—	1	4	4	—	4	5	—	—	—
Kathetostoma albigutta	—	—	—	—	4	14	5	12	10	—	1	—	—
Kathetostoma cubana	—	—	—	—	1	7	3	—	5	6	—	—	—
Gnathagnus egregius	—	—	—	2	19	1	—	—	—	—	—	18	4

Species	Numbers of pectoral rays (from each side of fish)																				
	13/14	14/14	14/15	15/15	15/16	16/16	16/17	17/17	17/18	18/18	18/19	19/19	19/20	20/20	20/21	21/21	21/22	22/22	22/23	23/23	23/24
Astroscopus y-graecum [a]	—	—	—	—	—	—	—	—	—	—	—	2	1	10	5	6	2	1	—	—	—
Astroscopus guttatus	—	—	—	—	—	—	—	—	—	—	—	1	2	3	2	1	—	—	—	—	—
Kathetostoma albigutta	1	—	3	15	2	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Kathetostoma cubana	—	—	—	—	—	—	—	4	3	4	—	—	—	—	—	—	—	—	—	—	—
Gnathagnus egregius [b]	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	5	12	7	3	1	1

[a] One specimen with a stunted pectoral fin and counts of 14/20.

[b] One specimen with counts of 20/22.

Museum; James E. Böhlke, Academy of Natural Sciences of Philadelphia; Antenor Leiatão de Carvalho, Museo Nacional, Rio de Janeiro; Frank S. Cliff, Colgate University; Bruce B. Collette, Cornell University; and Donald P. deSylva, University of Delaware. For making specimens available, we are indebted to Winfield Brady, Florida's Gulfarium; Harvey R. Bullis, Jr., U.S. Fish and Wildlife Service, Pascagoula; E. Milby Burton, Charleston Museum; Eugenie Clark, Cape Haze Marine Laboratory; Earl E. Deubler, Jr., University of North Carolina; Myvanwy M. Dick, Museum of Comparative Zoology; W. I. Follett, California Academy of Sciences; John D. Kilby, University of Florida; Giles W. Mead, U.S. Fish and Wildlife Service, Washington, D.C.; George S. Myers, Stanford University; C. Richard Robins and Walter R. Courtenay, Jr., University of Miami Marine Laboratory; Leonard P. Schultz, U.S. National Museum; Royal D. Suttkus, Tulane University; and Loren P. Woods, Chicago Natural History Museum.

We appreciate suggestions concerning the manuscript from the following of the staff of the U.S. Fish and Wildlife Service Biological Laboratory, Brunswick, Georgia: Jack W. Gehringer, David K. Caldwell, and Hugh M. Fields. We are also indebted to Joseph E. King and Daniel M. Cohen for review of the manuscript, and to the latter for securing the illustration of *Uranoscopus occidentalis*.

Taxonomic Treatment

Key to Western North Atlantic Uranoscopidae

1*a*. Spinous dorsal fin present (3 to 5 spines).

  2*a*. Top of head entirely covered by exposed cranial bones (apparently in all sizes); cleithral spines long, sharp pointed, and protruding through the skin. (*Uranoscopus* Linnaeus 1758; one species reported from Brazil.)
  Uranoscopus occidentalis Agassiz

  2*b*. Top of head partially covered by skin (plate 1) (in sizes over 34 mm. S.L. or 40 mm. T.L.); cleithral spines short, adpressed to body, bluntly pointed and covered with skin. (*Astroscopus* Brevoort 1860.)

    3*a*. Posterior end of rear nostril groove much closer to eye (orbit) than to posterior margin of skin-covered area over electric organs; distance from eye to end of rear nostril groove (a in plate 1G) about 1.9 to 11.0 times into distance from end of rear nostril groove to posterior margin of skin-covered area (b in plate 1G), in sizes above 40 mm. S.L. Y-shaped process on head usually long and narrow (plate 1), least width of its base about 1.4 to 2.4 percent of standard length at sizes larger than 100 mm. S.L. Top of head and body with large, widely spaced white spots (plate 2B). (North Carolina to Brazil.)
    Astroscopus y-graecum (Cuvier)

    3*b*. Posterior end of rear nostril groove usually closer to posterior margin of skin-covered area over electric organs than to eye (orbit) or not much closer to eye; distance from eye to end of rear nostril groove (a in plate 1G) about 0.5 to 1.6 times into distance from end of rear nostril groove to posterior margin of skin-covered area (b in plate 1G), in sizes above 40 mm. S.L. Y-shaped process on head usually short and broad (plate 1), least width of its base about 2.5 to 3.8 percent of standard length in sizes larger than 100 mm. S.L. Top of head and body with small, closely spaced, white spots (plate 2C). (North Carolina to New York.) **Astroscopus guttatus** Abbott

1*b*. Spinous dorsal fin absent.

4*a*. Lower jaw with a pair of prominent converging bony ridges on anterior part, deeply notched between (plate 4D). Preopercle with lower edge developed as a long flattened wing-like appendage, without true spines. Body with embedded scales (readily apparent at 100 mm. S.L. and larger). Cleithral spine flattened and bluntly pointed. (*Gnathagnus* Gill 1861; one species in western North Atlantic, Georgia to Texas.) **Gnathagnus egregius** (Jordan and Thompson)

4*b*. Lower jaw without a pair of prominent converging bony ridges on anterior part. Preopercle without winglike appendage but with three spines protruding from ventral margin. Body without scales. Cleithral spine long, conical, and sharply pointed. (*Kathetostoma* Günther 1860.)

5*a*. Pectoral rays 13 to 16. Dorsal fin with 2 or 3 distinct oblique black bars. Caudal fin with 2 to 5 horizontally elongated black spots. Upper part of body with distinct rounded or oblong white spots surrounded by dark margins. (North Carolina to Yucatan.) **Kathetostoma albigutta** Bean

5*b*. Pectoral rays 17 or 18. Dorsal fin without distinct bars, but with a single, rounded, indistinct blotch. Caudal fin without horizontally elongate black spots, but with a dark broad stripe about middle of fin. Upper part of body without distinct white spots, but irregularly marbled. (Off the Bahamas, Puerto Rico, Cuba, and Honduras.) **Kathetostoma cubana** Barbour

Genus *Uranoscopus* Linnaeus

Uranoscopus Linnaeus, Systema naturae, 1758, p. 250. Type species: *Uranoscopus scaber* Linnaeus, 1758, by monotypy.

Uranoscopus occidentalis Agassiz

PLATE 2A

Uranoscopus occidentalis Agassiz *in* Spix, 1831, p. 123, pl. LXXIII (type locality Atlantic Ocean, presumably on the coast of Brazil; type specimen presumably destroyed in the Munich Museum during World War II).—Valenciennes *in* Cuvier and Valenciennes, 1831, p. 492 (described after Agassiz, 1831).—Fowler, 1941, p. 178 (recorded after Agassiz, 1831).

Uranoscopus scaber (non Linnaeus), Kirsch, 1889, p. 261 (in part; reference to Agassiz, 1831; excluding reference to Günther's 1860 *U. occidentalis*).

Not *Uranoscopus occidentalis* Agassiz, Günther, 1860, p. 227 (specimens listed are from Mauritius, and Gulf of Guinea, West Africa).

SPECIMENS EXAMINED: No specimens seen by us.

SYNONOMY: Günther (1860, p. 227) listed as *Uranoscopus occidentalis* a stuffed adult specimen from the "West Indies" and two young specimens from the Gulf of Guinea, West Africa; Fowler (1936, p. 1033) included the reference of the young specimens in the synonomy of the Eastern Atlantic *Uranoscopus scaber* Linnaeus. G. Palmer of the British Museum (Natural History) in a communication of August 31, 1959, wrote regarding the adult specimen: "On checking the locality for the adult specimen, I find that the old register gives this as Mauritius and not the West Indies. It is part of a collection purchased by the Museum in 1841 from Stevens. The material was collected by Janvier, who certainly did work in the Mauritius area. I think the listing of the locality by Günther as the "West Indies" must be regarded as a *lapsus calami* on his part!" Agassiz's specimen may have been *Uranoscopus scaber* or some other species of *Uranoscopus*, but we record it as a distinct species because no other specimen of *Uranoscopus* has been reported from the American continents, and there is not sufficient evidence to warrant placing it in the synonymy of any other species.

DIAGNOSIS: Dorsal spines four. Dorsal soft rays 14. Anal soft rays 13 or 14. Pectoral rays 16. Lower jaw without a pair of prominent converging bony ridges. Top of head covered with exposed cranial bones. Cleithral spine long, sharp pointed, and protruding through the skin. Body scales present.

COLOR: Spinous dorsal fin black.

RANGE: Brazil (probably in the western South Atlantic), only the type specimen recorded.

Genus *Astroscopus* Brevoort

Astroscopus Brevoort *in* Gill, 1860, p. 20. Type species: *Uranoscopus anolopos* Valenciennes in Cuvier and Valenciennes, 1831, by monotypy.

Astroscopus y-graecum (Cuvier)

PLATES 1,A,C,E,G; 2B

Uranoscopus Y graecum Cuvier *in* Cuvier and Valenciennes, 1829, p. 308 (length quinze pouces; type locality unknown; type specimen deposition unknown).

Uranoscopus anoplos Valenciennes *in* Cuvier and Valenciennes, 1831, p. 493 (length deux pouces; type locality South Carolina from Mt. Le Conte; type specimen in Paris Museum ?).—DeKay, 1842, p. 37, pl. 22, fig. 65 (described; a 2.2-inch specimen from South Carolina collected by Le Conte; excluding reference to a sight record of a 6-inch specimen from New York Harbor).—Storer, 1846, p. 46 (reference after Cuvier and Valenciennes, 1831).

Agnus anoplus, Günther, 1860, p. 229 (reference after Cuvier and Valenciennes, 1831, and DeKay, 1842).

Uranoscopus y-graecum, Günther, 1860, p. 229 (described; an adult specimen from the "West Indies").—Gill, 1861b, p. 21 (referred to the genus *Astroscopus*).

Upselonphorus y-graecum, Gill, 1861a, p. 113 (reference).

Astroscopus anoplus, Gill, 1861a, p. 114 (reference, in part; excluding part of synonymy); 1861b, p. 43 (reference after Storer 1846).—Jordan and Gilbert, 1882, p. 629 (in part; excluding reference to Abbott, 1861, from synonymy).—Jordan, 1884, p. 139 (description; Key West, Fla.).

Astroscopus anolopos, Gill, 1861b, p. 21 (reference of this species to the new genus *Astroscopus* proposed by Brevoort through Gill).—Jordan and Evermann, 1898, p. 2308 (description of *A. anolopos* as a growth stage of *A. y-graecum*).

Astroscopus y-graecum, Bean, 1879, p. 58 (in part; described; St. Johns River, Matansas River Inlet, and Pensacola, Fla.; Charleston, S.C.; excluding record from Hampton Roads, Va.).—Jordan and Gilbert, 1882, pp. 628 and 941 (described); 1883, p. 610 (description; Charleston Harbor, S.C.).—Jordan and Evermann, 1898, p. 2307 (key; described; synonymy); 1900, p. 3301, pl. cccxxxiv, fig. 808 (Matanzas River Inlet, Fla.).—Evermann and Kendall, 1900, p. 92 (references, Fla.).—Smith, 1907, p. 371, fig. 170 (described; Bird Shoal, Beaufort Harbor, N.C.).—Weymouth, 1910, p. 140 (Cameron, La.).—White, 1918, p. 141 (development of electric organs; not distinguished from *A. guttatus*).—Meek and Hildebrand, 1928, p. 908 (small specimens from Atlantic coast of southern U.S. compared to small Pacific *A. zephyreus* Gilbert and Starks).—Hildebrand and Schroeder, 1928, p. 331, fig. 199 (compared with *A. guttatus;* Beaufort, N.C.).—Jordan, Evermann, and Clark, 1930, p. 454 ("South Atlantic Coast, from Cape Hatteras to the Caribbean Sea").—Fowler, 1941, p. 178 (Brazil, compiled); 1945, p. 152 (synonymy in part; Beaufort and New River Inlet, N.C.), p. 223 (Charleston Museum specimens from S.C.), p. 377 (Galveston, Tex.); 1953, p. 54 (Cartagena, Colombia).—Hildebrand, 1954, p. 348 (Texas Coast).—Springer and Bullis, 1956, p. 96 (*Oregon* station 82, 29°21.7′ N., 88°11′ W., 38 fathoms).—Anderson and Gehringer, 1957, p. 55 (34°38′ N., 76°33′ W., at Cape Lookout, N.C.).

Upsilonphorus y-graecum, Jordan, 1884, p. 140 (reference).

Astroscopus anolophus, Baird, 1884, p. 178 (Deal's Island, N.C.).

Anolophus V. graecum, Baird, 1884, p. 178 (reference).

Astroscopus anoplos, Kirsch, 1889, p. 262 (in part; length 1¼ inches, Key West, Fla.; excluding part of range).

Upsilonphorus Y-graecum, Kirsch, 1889, p. 263 (described; Pensacola, Fla., and Beaufort, N.C.).

Astroscopus guttatus (non Abbott), Weymouth, 1910, p. 140 (Cameron, La.).—Dahlgren, 1927, figs. 1 and 3 (these figures only; other references to *A. guttatus* apply or may apply to *A. guttatus*).

Astroscopus Y-graecum, Dahlgren, 1927, p. 364, fig. 11 (life history notes, possibly referable to this species; anatomy).

SPECIMENS EXAMINED

Off Cape Hatteras, N.C., 3 miles SSW of Diamond Shoals Lightship, Mar. 22–25, 1957 (1 specimen), 170 mm. S.L., UNC 2679. Cape Lookout Anchorage, N.C., *Gill* Cr. 4, Nov. 11–12, 1953 (1), 167 mm. SL , BLBG. Gallants Channel at Beaufort railroad bridge, N.C., Jan. 18, 1957 (1), 15.5 mm. S.L , UNC 924. Shackleford Banks, Beaufort, N.C., Sept. 4, 1925 (1), 135 mm. S.L., USNM 185681. Beaufort, N.C., collectors Gudger and Bean (1), 200 mm. S.L., USNM 51912. Beaufort, N.C., collector O. P. Jenkins (1), 84 mm. S.L., CAS (IU No. 6111). Bogue Sound near Swainsboro, N.C., July 17, 1956 (1), 187 mm. S.L., UNC 2370. West shore off Cape Fear River at Southport, N.C., Dec. 12, 1956 (2), 22.5–30 mm. S.L., UNC 866.

North Island at Wingate Bay, S.C., *Fish Hawk* (1), 33 mm. S.L., USNM 59055. Coosan River, S.C. (3), 26–41 mm. S.L., USNM 59083. Coosan River, S.C. (3), 26.5–41 mm. S.L., USNM 59091. South Carolina (2), 29–46.5 mm. S.L., USNM 59033.

Savannah, Ga., collector I. R. Tompkins (4), 32.5–38 mm. S. L., USNM 117198 Off Brunswick, Ga., Feb. 2, 1931, collector W. W. Anderson (1), 41 mm. S.L., USNM 111505. Commercial Trawling Area, Brunswick, Ga., Jan. 16, 1957 (2), 57.5–61 mm. S.L.; Mar. 25, 1959 (1), 59 mm. S.L.; July 13–14, 1959 (1), 120 mm. S.L.; July 14, 1959 (1), 117 mm. S.L.; Oct. 3, 1956 (2), 97.5–112 mm. S.L.; Oct. 20, 1955 (2), 113–127 mm. S.L.; Oct. 22, 1955 (1), 142 mm. S.L.; Nov. 22, 1955 (1), 145 mm. S.L., BLBG. Jekyll Island Causeway, Ga., Nov. 28, 1958 (1), 18 mm. S.L., BLBG. East Beach, St. Simons Island, Ga., Feb. 15, 1956 (1), 18.5 mm. S.L.; Mar. 5, 1957 (1), 25.5 mm. S.L.; Mar. 12, 1959 (1), 28 mm. S.L.; Apr. 13, 1956 (1), 42.5 mm. S.L.; Apr. 16, 1957 (3), 36.5–49.5 mm. S.L.; Apr. 27, 1956 (4), 31.5–47.5 mm. S.L.; May 14, 1956 (3), 44–62 mm. S.L.; May 28, 1956 (4), 41–58 mm. S.L.; July 15, 1957 (1), 81 mm. S.L.; Dec. 19, 1955 (1), 18 mm. S.L.; BLBG. King and Prince Beach, St. Simons Island, Ga., Jan. 15, 1954 (1), 24.5 mm. S.L.; Jan. 16, 1956 (1), 22.4 mm. S.L.; Jan. 27, 1959 (3), 14.5–50 mm. S.L.; Feb. 11, 1959 (1), 19.5 mm. S.L.; Feb. 15, 1956 (1), 25.5 mm. S.L.; Feb. 26, 1959 (1), 19.5 mm. S.L.; Feb. 29, 1956 (1), 48.5 mm. S.L.; Mar. 5, 1957 (10), 42.5–66.5 mm. S.L.; Mar. 15, 1956 (1), 33.5 mm. S.L.; Mar. 18, 1957 (6), 23.5–63.5 mm. S.L.; Apr. 3, 1957 (1), 55 mm. S.L.; Apr. 8, 1955 (1), 24.5 mm. S.L.; Apr. 25, 1955 (1), 30.5 mm. S.L.; May 2, 1957 (2), 60–60.5 mm. S.L.; May 14, 1956 (2), 17–39 mm. S.L.; May 16, 1957 (5), 48.5–68.5 mm. S.L.; May 25, 1959 (1), 22 mm. S L.; May 31, 1957 (2), 51–71 mm. S.L.; June 14, 1957 (1), 69 mm. S L.; Sept. 11, 1957 (1), 124 mm. S.L.; Sept. 16, 1958 (1), 119 mm. S.L.; Nov. 28, 1958 (1), 40 mm. S.L.; Dec. 2, 1955 (1), 49 mm. S.L.; Dec. 4, 1956 (2), 12.5–21.5 mm. S.L.; Dec. 19, 1956 (2), 14.5–39.5 mm. S.L.; Dec. 19, 1955 (2), 12–19 mm. S.L.; BLBG. St. Simons Island, Ga., Nov. 21, 1930 (1), 36 mm. S.L., USNM 119233. Brickhill Creek, Camden County, Ga., Jan. 1931 (13), 33.5–43.5 mm. S.L., USNM 126065.

St. Johns River, Fla., collector S. F. Baird (1), 118 mm. S.L., USNM 18044. West of North Key, Florida Keys, 2.5 fathoms, Mar. 25, 1957 (1), 182 mm. S.L., UF. Key West, Fla. (1), 25 mm. S.L., CAS (IU No. 6344). Key West, Fla., collector D. S. Jordan (1), 24.5 mm. S.L., USNM 35002. Lemon Bay, Fla., summer 1953 (1), 105 mm. S.L., CHML. Lemon Bay at Grove City, Fla., Jan. 28, 1955 (1), 41.5 mm. S.L., CHML. South Englewood Beach, Fla., May 25, 1955 (1), 83 mm. S.L., CHML. Vicinity of Ft. Walton, Fla., summer 1959, collector The Gulfarium (1), 323 mm. S.L., BLBG. Pensacola, Fla., Feb. 9, 1885 (4), 21.3–39 mm. S.L., USNM 132272. Pensacola, Fla., collector Harrison (1), 140 mm. S.L., USNM 44870. Pensacola, Fla., collector Jordan and Stearns (1), 38 mm. S.L., USNM 30851. Florida, collector J. C. Willetts (1), 230 mm. S.L., USNM 18029. 30°12′ N., 88°40′ W., *Silver Bay* Station 167, 4 fathoms, Aug. 28, 1957 (1), 186 mm. S.L., USNM 159669.

Four Bayou Pass, La., Feb. 18, 1933 (1), 42.5 mm. S.L., USNM 185647. Louisiana, Nov. 28, 1931 (5), 23.8–90 mm. S.L., USNM 185669. Off Louisiana coast, 1932 (1), 39 mm. S.L., USNM 156863.

Galveston, Tex., 1941 (1), 120 mm. S.L., USNM 120039. Galveston, Tex., collector D. S. Jordan (1), 50.5 mm. S.L., USNM 30898. Aransas Pass, Corpus Christi, Tex., Nov. 5, 1926 (9), 11.1–17.1 mm. S.L., USNM 185650. Aransas Pass, Tex., Apr. 5, 1927 (1), 144 mm. S.L., USNM 185682. Texas (2), 20–32 mm. S.L., USNM 185675.

Port of Fortaleza, Macuripe, Brazil, Mar. 1945 (1), 48 mm. S.L., SU 52345.

SYNONYMY: *Astroscopus y-graecum* and *A. guttatus* have frequently been confused, due partly to the failure to recognize growth changes in head sculpture in the two species. In earlier years it was due also to the recognition of a third nominal species of this group, *Astroscopus anolopos*, apparently based on a small specimen of *A. y-graecum* that still had the larval character of the head covered by the exposed cranial bones. We have not examined larval specimens of *A. guttatus* and therefore cannot distinguish them from larval *A. y-graecum* other than by distribution. Larval specimens of *Astroscopus* from the North Carolina coast, where the ranges of the two species are known to overlap, are identified only to genus; specific identifications of larvae from north and south of North Carolina are presumptive. In a publication containing many life history notes and theories, Dahlgren (1927) discussed both *Astroscopus y-graecum* and *A. guttatus* and stated (p. 364): "Where they overlap in the neighborhood of Cape Hatteras it seems practically certain that they interbreed, and great variation is found." Dahlgren did not, however, record his criteria for separation of the two species, and we are convinced that he misidentified some of his specimens (see synonymies).

Diagnosis: Dorsal spines III to V. Dorsal soft rays 13 to 15. Anal soft rays 12 to 14. Pectoral rays 19 to 22. Pelvic rays I, 5. Pelvic girdle without exposed anteriorly directed spines. Top of head covered by exposed cranial bones to about 31 mm. S.L.; in larger sizes the frontal bones exposed posteriorly on the head, with their medial processes forming an exposed Y-shaped process that extends anteriorly between the eyes, and with the area within the fork of the Y and lateral to it covered by skin; with growth the basal arm of the Y becomes long and narrow and the fleshy area becomes comparatively large; least width of the basal arm of the Y about 1.4 to 2.4 percent of standard length at sizes larger than 100 mm. S.L. Posterior nostrils each in a fringed groove curving around behind the eye; posterior end of nostril groove much closer to back of eye than to posterior margin of skin-covered area over electric organs; distance from eye to end of rear nostril groove (a in plate 1G) into distance from end of rear nostril groove to posterior margin of skin-covered area (b in plate 1G) about 1.9 to 11.0 times (in sizes above 40 mm. S.L.). Lower jaw without a pair of prominent converging bony ridges.

Preoperculum and operculum without spines or processes above about 35 mm. S.L. (in smaller sizes the preoperculum has a blunt angle spine, and a bluntly pointed spine is present at the upper anterior margin of the operculum). Cleithral spine small, laterally compressed, covered by skin and adpressed to body. Scales present on body and extending onto fleshy part of caudal fin; scales absent on head, an area posterior to the pectoral fin bases, the throat and abdomen, between the lateral lines and the dorsal fin, and a narrow area along the anal fin base. Lateral lines on each side of body extending from head along back close to dorsal fin, bending down through central part of caudal base onto fleshy part of caudal fin, then bending anteroventrally to unite at bottom of caudal base.

Color: Body and head generally dark above and light below; tip of lower jaw and upper part of head and body to end of dorsal base with large, irregular, widely spaced white spots having narrow dark margins (these spots not formed on specimens less than about 47 mm. standard length); a dark stripe extending along middle of caudal peduncle; a large elongated black blotch on each side of chin. Spinous dorsal fin black. Soft dorsal fin with from one to three oblique black bars (one bar present between about 50 and 70 mm. standard length, two bars between about 55 and 130 mm., three bars above about 120 mm.). Anal fin with an elongated black stripe extending across most of the softrays (formed between about 53 and 60 mm. standard length). Pectoral fins dusky over most of fin, tending to become black near tip, with a narrow light margin (pigment becoming pronounced at about 50 mm. standard length). Pelvics with an elongated dusky or blackish spot near the distal end of the inner rays (forming at about 110 mm. standard length). Caudal fin with one or three black stripes (one stripe formed at about 40 mm. standard length, three stripes formed at about 55 mm.).

Size: Largest specimen examined, 323 mm. S.L. (440 mm. or 17.5 inches total length). Smallest specimen examined, 12 mm. S.L.

Range: From Cape Hatteras, North Carolina, southward along the United States Atlantic and Gulf coasts and the coast of Central and South America to Santos, Brazil. From recorded specimens this species appears to be an inshore, relatively shallow water inhabitant. Springer and Bullis (1956, p. 96) recorded the species from one *Oregon* station at 38 fathoms from off Alabama—apparently the greatest depth to be recorded.

***Astroscopus guttatus* Abbott**

Plates 1b,d,f; 2c

Astroscopus guttatus Abbott, 1861, p. 365, pl. 7 (type locality Cape May, New Jersey, Beesley's Point ?); type specimen in Academy of Natural Sciences of Philadelphia, No. 22722, about 118 mm. S.L; not *Uranoscopus guttatus* Cuvier 1829, a *Uranoscopus* described from the coast of Pondicherry, India).—Gill, 1861b, p. 43 (reference after Abbott 1861).—Jordan and Evermann, 1898, p. 2307 (key), p. 2310 (description; distinguished from *Astroscopus y-graecum*).—Shufeldt, 1901, pl. vii (photograph).—Fowler, 1906, p. 399 (key), p. 401 (redescription of type specimen from Cape May, 6.5 inches in length).—Evermann and Hildebrand, 1910, p. 163 (Gloucester Point, Va.).—Fowler, 1916, p. 42 (Sandy Hook, N.J.).—White, 1918, p. 141 (development of electric organs; not distinguished from *A. y-graecum*).—Fowler, 1925, p. 45 (Young's Pier, Atlantic City, N.J.); 1926, p. 150 (Longport, N.J.).—Dahlgren, 1927, p. 364, figs. 2, 4–5 (in part; life history notes, possibly referable to this species; excluding figs. 1 and 3 which are *A. y-graecum*).—Nichols and Breder, 1927, p. 156, fig. 228 (accidental distribution in the fall in New York).—Hildebrand and Schroeder, 1928, p. 330, fig. 200 (described; compared with *A. y-graecum;* Lewisetta, Buckroe Beach, Lynnhaven Roads, and Ocean View, Va.).—Jordan, Evermann, and Clark, 1930, p. 454 ("Atlantic coast of the United States, from Long Island to Virginia; not known south of Cape Hatteras").—Pearson, 1941, p. 99, figs. 24–25 (larvae illustrated; Chesapeake Bay, Va.).—Fowler, 1945, p. 72 (synonymy in part; Little Assawoman Bay, Worcester County, Md.).—O'Brien, 1955, p. 90 (photographs).

Upselonphorus guttatus, Gill, 1861a, p. 113 (reference, in part, range incorrect).

Astroscopus anoplus (non Valenciennes), Uhler and Lugger, 1876, p. 83 (synonymy in part; "Occurs occasionally in the southern part of Chesapeake Bay").—Bean, 1879, p. 60 (described; Tompkinsville, N.Y., and Norfolk, Va.).—Jordan and Gilbert, 1882, p. 629 (in part; reference to Abbott, 1861, only), p. 941 (described).

Astroscopus y-graecum (non Cuvier), Bean, 1879, p. 58 (in part; record from Hampton Roads, Va., only).—Fowler, 1906, p. 399, pl. 91 (key to growth stages of *A. guttatus;* description; Atlantic City, N.J., 14-inch specimen).

Upsilonphorus guttatus, Jordan, 1884, p. 140 (reference).—Kirsch, 1889, p. 264 (reference).

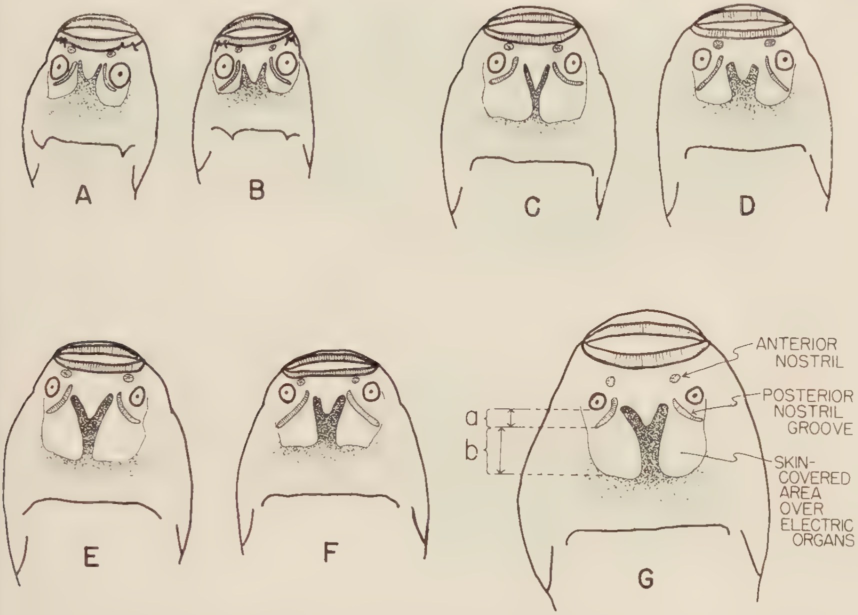
SPECIMENS EXAMINED

Astroscopus guttatus: Rockaway, Long Island, N.Y., collector Blackford (1), 37 mm. S.L., USNM 34628. Tompkinsville, N.Y., collector Charles Copley (1), 80 mm. S.L., USNM 10761. Longport, N.J., Aug. 26, 1887, collector T. H. Bean (1), 48.5 mm. S.L., USNM 45112. Barnegat Bay, N.J., Sept. 19, 1928, collector R. G. Collins (1), 71.5 mm. S.L., USNM 89062. Chesapeake Bay, collector Otto Lugger (3), 43–65.5 mm. S.L., USNM 39347.

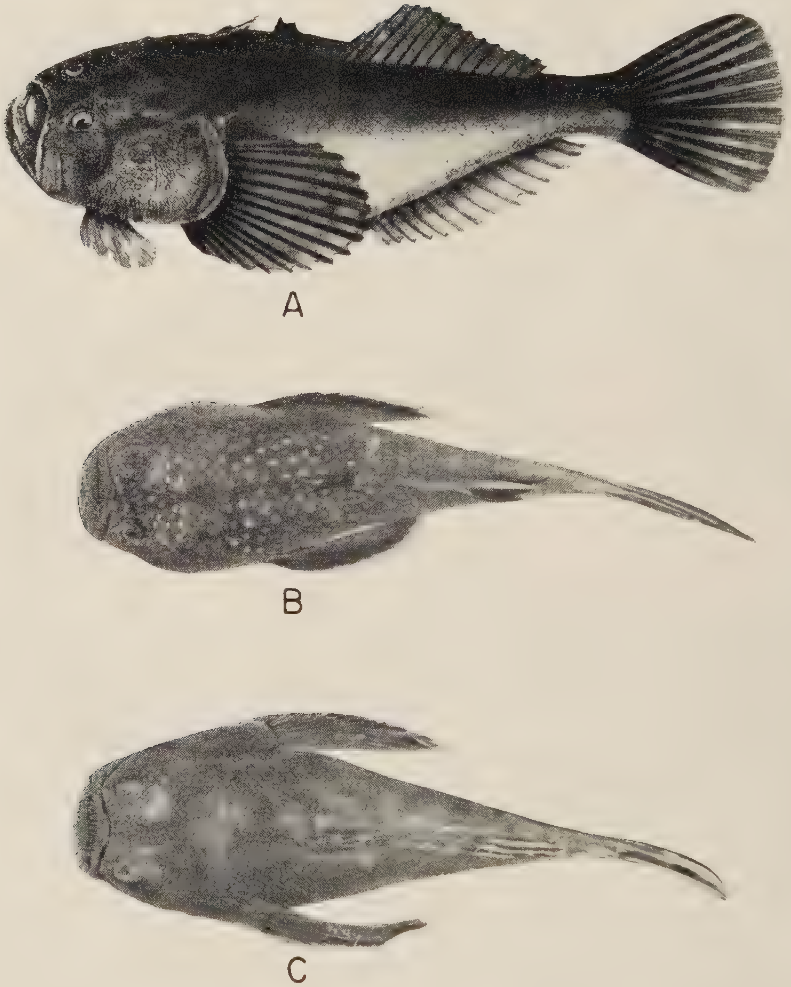
Old Point, Va., Apr. 10, 1922 (1), 70 mm. S.L., USNM 91208. Old Point Comfort, Va., Sept. 11, 1908 (2), 150–155 mm. S.L., USNM 73517. Gloucester Point, York River, Va., *Fish Hawk*, Apr. 3, 1892 (1), 54 mm. S.L., USNM 67917. Buckroe Beach, Va., Oct. 5, 1921 (2), 45–80 mm. S.L., USNM 91209. Off Buckroe Beach, Chesapeake Bay, Va., Apr. 3, 1930 (1), 91.5 mm. S.L., USNM 185668. Fortress Monroe, Va., *Grampus*, June 28, 1892 (1), 95 mm. S.L., USNM 125018. Ocean View, Norfolk, Va., Oct. 16–18, 1922, collector W. C. Schroeder (1), 98 mm. S.L., USNM 91207. Ocean View, Norfolk, Va., Oct. 10–13, 1922 (7), 69.5–105 mm. S.L., USNM 91206. Ocean View, Norfolk, Va., Sept. 5 to Oct. 7, 1922 (7), 58.5–104 mm. S.L., USNM 185683. Norfolk, Va., collector U. Dahlgren (1), 187 mm. S.L., USNM 57830. Norfolk, Va. (1), 207 mm. S.L., USNM 4622. The Cape, N.C., collector M. Corbel (1), 215 mm. S.L., USNM 32754. Off Cape Hatteras, N.C., 10–20 fathoms, Dec. 5, 1930 (1), 197 mm. S.L., USNM 185684. Cape Lookout, N.C., collector Coles (1), 119 mm. S.L., USNM 74308.

Astroscopus sp.: 35°25′30″ N., 75°25′00″ W., *Albatross* station 2286, Oct. 19, 1884 (1), 34 mm. S.L., USNM 131500. 35°22′50″ N., 75°25′00″ W., *Albatross* station 2289 (1), 22.8 mm. S.L., USNM 148208. Mouth of canal, Beaufort, N.C., Feb. 13, 1930 (1), 25.2 mm. S.L., USNM 153674. Mouth of canal, Beaufort, N.C., Mar. 13, 1931 (1), 24.2 mm. S.L., USNM 153675. Newport River, Beaufort, N.C., Jan. 2, 1930 (1), 23.7 mm. S.L., USNM 153676.

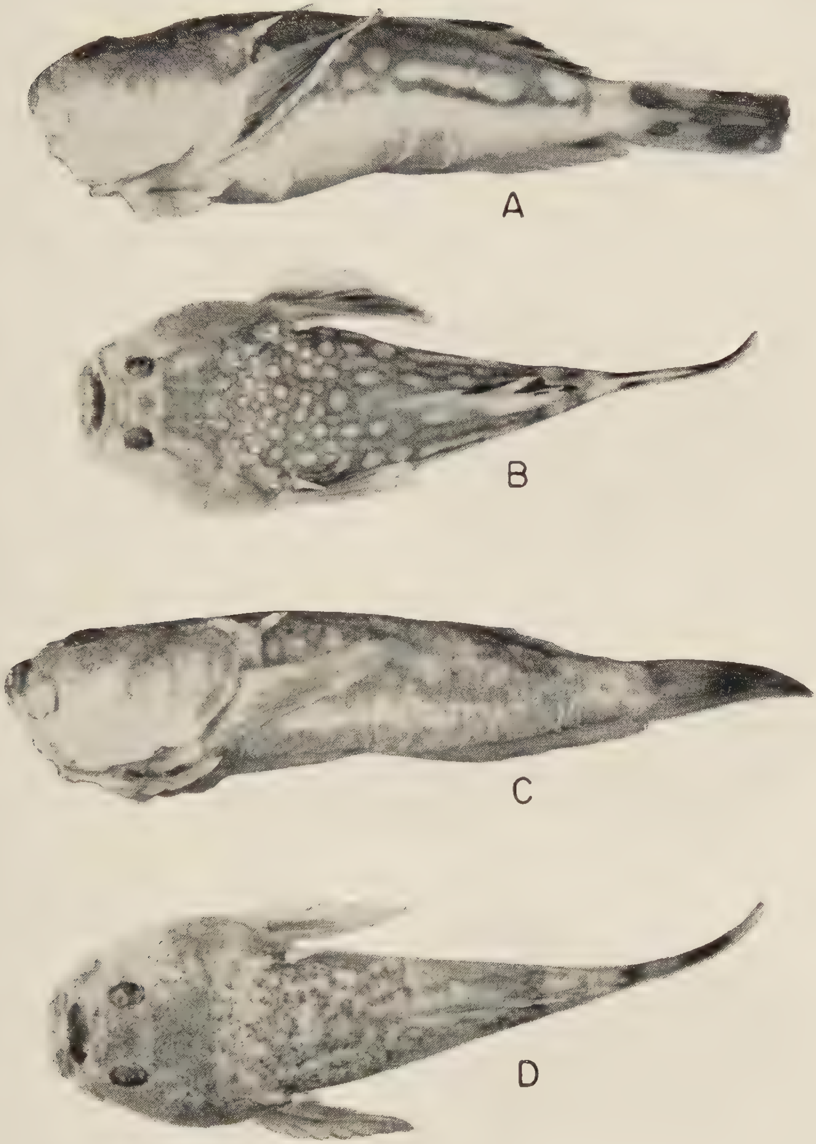
DIAGNOSIS: Dorsal spines IV or V. Dorsal soft rays 13 to 15. Anal soft rays 13 or 14. Pectoral rays 19 to 21. Pelvic rays I, 5. Pelvic girdle without exposed anteriorly directed spines. Top of head covered by exposed cranial bones at small sizes (at 23 mm. T.L., fide


A
B
C
D
ANTERIOR NOSTRIL
a
b
POSTERIOR NOSTRIL GROOVE
SKIN-COVERED AREA OVER ELECTRIC ORGANS
E
F
G

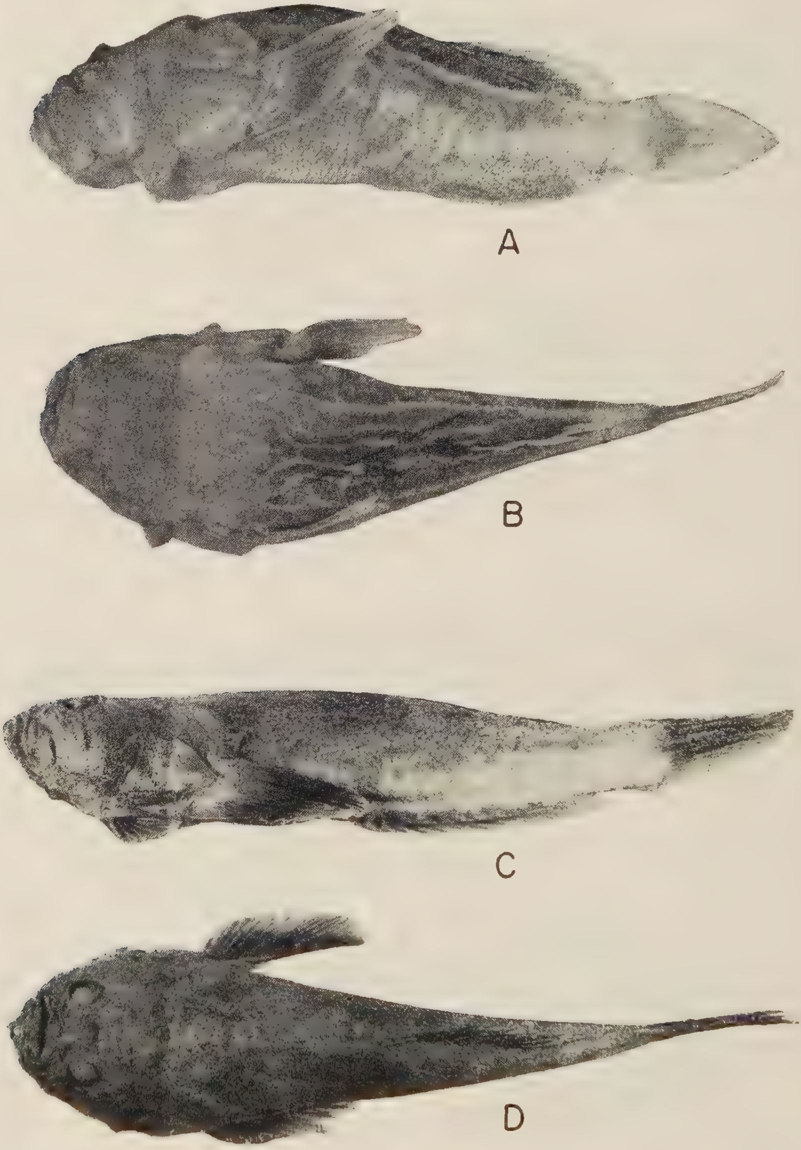
Diagrammatic dorsal view of heads of *Astroscopus y-graecum* and *Astroscopus guttatus* illustrating growth changes in shape or relative position of the Y-shaped processes of the frontal bones, the posterior nostril groove and the area of skin covering the electric organs. *Astroscopus y-graecum:* A, 45 mm. S.L.; C, 112 mm. S.L.; E, 14 inches total length; G, 323 mm. S.L. (17.5 inches total length). *Astroscopus guttatus:* B, 45 mm. S.L.; D, 98 mm. S.L.; F, 12 inches total length. E and F modified from Dahlgren (1927, figs. 4 and 11). The measurements shown in G are: a, distance from eye to rear end of posterior nostril groove; b, distance from rear and of posterior nostril groove to posterior margin of skin-covered area.



A, *Uranoscopus occidentalis*, drawing of the type, after Agassiz *in* Spix (1831, pl. LXXIII). B, *Astroscopus y-graecum*, 100 mm. S.L., Brunswick, Ga., BLBG. C, *Astroscopus guttatus*, 98 mm. S.L., Norfolk, Va., USNM 91207.



A and B, *Kathetostoma albigutta*, 113 mm. S.L., *Combat* station 454, 25°13′ N., 80°10′ W., BLBG. C and D, *Kathetostoma cubana*, 119 mm. S.L., *Silver Bay* station 441, 27°39′ N., 79°15′ W., BLBG.



Gnathagnus egregius: A and B, 76 mm. S.L., *Oregon* station 265, 29°20′ N., 87°42′ W., CNHM 46649. C and D, 243 mm. S.L., *Oregon* stations 472 through 478, Gulf of Mexico off Mississippi Delta, CNHM 46651.

Pearson 1941, p. 98, fig. 25); in larger sizes (at least by 43 mm. S.L.) the frontal bones exposed posteriorly on the head, with their medial processes forming an exposed Y-shaped process that extends anteriorly to between or just behind the eyes, and with the area within the fork of the Y and lateral to it covered by skin; in large specimens the basal arm of the Y short and broad and the skin-covered area only moderately enlarged; least width of the basal arm of the Y about 2.5 to 3.8 percent of standard length in sizes larger than 100 mm. S.L. Posterior nostrils each in a fringed groove curving around behind the eye; posterior end of nostril groove usually closer to posterior margin of skin-covered area over electric organs than to eye or not much closer to eye; distance from eye to end of rear nostril groove (a in plate 1G) into distance from end of rear nostril groove to posterior margin of skin-covered area (b in plate 1G) about 0.5 to 1.6 times (at sizes above 40 mm. S.L.). Lower jaw without a pair of prominent converging bony ridges.

Preoperculum and operculum without spines or processes. Cleithral spine small, laterally compressed, covered by skin and adpressed to body. Scales present on body and extending onto fleshy part of caudal fin; scales absent on head, an area posterior to the pectoral fin bases, the throat and abdomen, between the lateral lines and the dorsal fin, and a narrow area along the anal fin base. Lateral lines on each side of body extending from head along back close to dorsal fin, bending down through central part of caudal base onto fleshy part of caudal fin, then bending anterioventrally to unite at bottom of caudal base.

Color: Body and head generally dusky above and light below; tip of lower jaw and upper part of head and body to end of dorsal base with many small and irregular white spots; a dark stripe extending along middle of caudal peduncle; a large elongated black blotch on each side of chin. Spinous dorsal fin black. Soft dorsal fin with about 4 oblique black bars. Anal fin with an elongated blackish stripe extending across most of the soft rays. Pectoral fins dusky over most of fin, tending to become black near tip, and with a narrow light margin. Pelvic fins mostly clear with a dusky or dark spot between distal ends of last two rays. Caudal fin with about three black stripes.

Size: Largest specimen reported, 12¼ inches total length (about 220 mm. S.L.), from Chesapeake Bay (Hildebrand and Schroeder, 1927, p. 331). Smallest specimens reported, 2.5 to 5 mm. T.L. and 23 mm. T.L. (Pearson, 1941, p. 98, figs. 24–25). Largest specimen examined 215 mm. S.L. Smallest specimen examined 37 mm. S.L. Dahlgren (1927, p. 358) reported specimens as *Astroscopus* (presumably this species) from several miles off the Virginia coast that were up to 22 inches in total length and weighed up to 15 or 20 pounds.

RANGE: From Long Island, New York, to Cape Lookout, North Carolina. This species primarily inhabits inshore, shallow, sandy areas. Dahlgren (1927, p. 362) speculated that larger individuals spawned at depths of 30 to 200 feet.

Genus *Kathetostoma* Günther

Kathetostoma Günther, 1860, p. 231. Type species: *Uranoscopus laevis* Bloch and Schneider, 1801, by monotypy.

Kathetostoma albigutta Bean

PLATE 3A-B

Cathetostoma albigutta Bean, 1892, p. 121 (type specimens in U.S. National Museum. Type locality *Albatross* station 2403, 28°42′30″ N., 85°29′00″ W., 88 fathoms, USNM 39304, holotype 119 mm. S.L. and one paratype 115 mm. S.L. Paratypes from *Albatross* station 2404, 28°44′ N., 85°16′ W., 60 fathoms, USNM 39305 (2), 85 and 113 mm. S.L.; *Albatross* station 2410, 26°47′30″ N., 83°25′15″ W., 28 fathoms, USNM 39306 (1), 95 mm. S.L.; and *Albatross* station 2411, 26°33′30″ N., 83°15′30″ W., 27 fathoms, USNM 39307 (1), 27.5 mm. S.L.).

Kathetostoma albigutta, Jordan and Evermann, 1898, p. 2311 (key), p. 2312 (described; incorrectly stated that only one specimen known; dorsal and anal ray counts incorrect); 1900, p. 3301, pl. CCCXXXIV, figs. 809, 809a (type specimen illustrated).—Longley and Hildebrand, 1940, p. 267 (reference).—Barbour, 1941, p. 1 (reference to holotype).—Longley and Hildebrand, 1941, p. 245 (described; off Tortugas, Fla., 67 to 88 fathoms).—Hildebrand, 1954, p. 317 (off Gulf coast of Texas and northern Mexico).—Springer and Bullis, 1956, p. 97 (*Oregon* stations in the Gulf of Mexico).

Kathetostoma albiguttum, Evermann and Kendall, 1900, p. 92 (reference to type specimen localities).

SPECIMENS EXAMINED

34°52′ N., 75°27′ W., *Silver Bay* station 1283, 98 fathoms, Sept. 17, 1959 (1), 115 mm. S.L., BLBG. 34°48′ N., 75°33′ W. to 34°45.5′ N., 75°28′ W., *Albatross* III station 35, tow 1, 42–48 fathoms, June 3, 1945 (1), 80 mm. S.L., USNM 151918. 34°32′ N., 75°58′ W. to 34°34′ N., 75°58′ W., *Albatross* III Cr. 21, station 5, tow 1, 23–25 fathoms, June 8, 1949 (2), 120–121 mm. S.L., USNM 151923. 34°23′ N., 76°03′ W., *Combat* station 408, 30 fathoms, June 22, 1957 (1), 105 mm. S.L., USNM 159644. 34°17′ N., 76°01′ W., *Combat* station 406, 45 fathoms, June 21, 1957 (1), 36 mm. S.L., BLBG. 34°17′ N., 76°01′ W., *Combat* station 406 (1), 117 mm. S.L., USNM 159646. 34°11′ N., 76°18′ W., *Pelican* station 187-2, 22 fathoms, Feb. 27, 1940 (1), 90.5 mm. S.L., USNM 185649. 33°55.5′ N., 76°23′ W., to 33°59′ N., 76°20′ W., *Albatross* III Cr. 31-A, station 1, tow 4, 78 fathoms, Jan. 18, 1950 (2), 116–126 mm. S.L., USNM 151935.

Southeast of North Edisto River sea buoy, S.C., 20 fathoms, Feb. 24, 1958 (1), 105 mm. S.L., CM 58.2.19. 32°34′ N., 78°46′ W., *Combat* station 424, 24 fathoms, June 24, 1957 (1), 104 mm. S.L., TU 17087. 32°26′ N., 79°03′ W., *Combat* station 167, 23 fathoms, Nov. 1, 1956 (1), 106 mm. S.L., UF 7229. 32°05′ N., 79°40′ W., *Combat* station 514, 22–25 fathoms, Oct. 7, 1957 (1), 110 mm. S.L., USNM 159645. 31°55′ N., 79°35′ W., *Combat* station 518, 38–43 fathoms, Oct. 8, 1957 (1), 162 mm. S.L., TU 17552. 31°49′ N., 79°31′ W., *Combat* station 519, 45 fathoms, Oct. 8, 1957 (1), 88 mm. S.L., TU 17561. 31°38′ N., 79°40′ W., *Combat* station

526, 41–45 fathoms, Oct. 8, 1957 (1), 82 mm. S.L., TU 17600. 31°29′ N., 79°33′ W., *Combat* station 512, 60 fathoms, Oct. 3, 1958 (1), 115 mm. S.L., USNM 159097. 31°18′ N., 79°45′ W., *Combat* station 528, 100 fathoms, Oct. 9, 1957 (2), 118–157 mm. S.L., TU 17556. 31°00.5′ N., 80°01.5′ W., *Pelican* station 198–1, 40 fathoms, Mar. 15, 1940 (1), 29 mm. S.L., USNM 185666.

20 to 50 fathom contour from point north of Jacksonville, Fla., to a point south of Brunswick, Ga., *Bowers*, Jan. 1956, collector James D. Regan (1), 121 mm. S.L., UMML 5. 30°13′ N., 80°23′ W., *Combat* station 497, 25 fathoms, Aug. 20, 1957 (1), 94.5 mm. S.L., BLBG. 29°30′ N., 80°13′ W., *Combat* station 488, 50 fathoms, Aug. 19, 1957 (3), 99–107 mm. S.L., BLBG. 29°15′ N., 80°13′ W., *Combat* station 334, 30 fathoms, June 1, 1957 (1), 85 mm. S.L., BLBG. 29°03′ N., 80°13′ W., *Combat* station 335, 28 fathoms, June 1, 1957 (1), 147 mm. S.L., USNM 159389. 28°58′ N., 80°13′ W., *Combat* station 333, 30 fathoms, June 1, 1957 (3), 102–144 mm. S.L., BLBG. 25°13′ N., 80°10′ W., *Combat* station 454, 85 fathoms, July 26, 1957 (6), 87.5–142 mm. S.L., BLBG. South of Tortugas, Fla., collector W. H. Longley (6), 72.5–113 mm. S.L., USNM 92057.

Tortugas, Fla., collector W. H. Longley (4), 80–101 mm. S.L., USNM 117281. 24°47′ N., 83°13′ W., *Oregon* station 1020, 35 fathoms, Apr. 19, 1954 (1), 96 mm. S.L., USNM 185648. 26°33′30″ N., 83°15′30″ W., *Albatross* station 2411, 27 fathoms (1 paratype), 27.5 mm. S.L., USNM 39307. 24°25′ N., 83°22′ W., *Oregon* station 1548, 210 fathoms, June 17, 1956 (1), 90 mm. S.L., TU 12683. 26°47′30″ N., 83°25′15″ W., *Albatross* station 2410, 28 fathoms (1 paratype), 95 mm. S.L., USNM 39306. 27°30′ N., 84°14′ W., *Oregon* station 937, 38 fathoms, Mar. 18, 1954 (1), 105 mm. S.L., UF 3708. 28°44′ N., 85°16′ W., *Albatross* station 2404, 60 fathoms (2 paratypes), 85–113 mm. S L., USNM 39305. 28°47′ N., 85°19′ W., *Oregon* station 895, 64 fathoms, Mar. 7, 1956 (3), 88.5–111 mm. S.L., TU 12959. 28°42′30″ N., 85°29′ W., *Albatross* station 2403, 88 fathoms (holotype and 1 paratype), 119–115 mm. S.L., USNM 39304. 29°07.5′ N., 85°40.5 W., *Pelican* station 154–3, 50 fathoms, Mar. 10, 1939 (1), 72 mm. S.L., USNM 185646.

29°36′ N., 85°54′ W., *Silver Bay* station 160, 21–22 fathoms, Aug. 23, 1957 (1), 136 mm. S.L., USNM 159658. 29°32′ N., 86°04′ W., *Silver Bay* station 158, 40 fathoms, Aug. 23, 1957 (3), 110–122 mm. S.L., USNM 159660. 29°47′ N., 86°28.5′ W., *Pelican* station 143–3, 60 fathoms, Mar. 5, 1939 (1), 113 mm. S.L., USNM 185680. 29°50′ N., 86°35′ W., *Silver Bay* station 316, 60–75 fathoms, Mar. 16, 1958 (1), 108 mm. S.L., BLBG. 30°03′ N., 86°50′ W., *Silver Bay* station 312, 55 fathoms, Mar. 16, 1958 (1), 101 mm. S.L., BLBG. 30°03′ N., 86°50′ W., *Silver Bay* station 312 (1), 204 mm. S.L., TU 17561. 30°03′ N., 86°56′ W., *Oregon* station 331, 60 fathoms, May 4, 1951 (1), 98.5 mm. S.L., USNM 186170. 28°11′ N., 91°24.5′ W., *Pelican* station 85–4, 47 fathoms, July 12, 1938 (1), 96.5 mm. S.L., USNM 185671. 28°09′ N., 91°32′ W., *Pelican* station 85–2, 49 fathoms, July 12, 1938 (1), 111 mm. S.L., USNM 185670.

27°45′ N., 96°13′ W., *Pelican* station 108–10, 39 fathoms, Jan. 23, 1939 (2), 84.5–92 mm. S.L., USNM 185673. 27°24.5′ N., 96°13′ W., *Pelican* station 40, 90 fathoms, Apr. 21, 1938 (1), 108 mm. S.L., USNM 185672. 27°29′ N., 96°16′ W., *Oregon* station 159, 58 fathoms, Nov. 27, 1950 (1), 85 mm. S.L., TU 2674. 27°27′ N., 96° 17′ W., *Oregon* station 158, 65 fathoms, Nov. 27, 1950 (4), 102–145 mm. S.L., USNM 185685. 27°17.5′ N., 96°25′ W., *Pelican* station 111–4, 75 fathoms, Jan. 30, 1939 (2), 78–92.5 mm. S.L., USNM 185667. 26°10′ N., 96°40′ W., *Oregon* station 1087, 29 fathoms, June 3, 1954 (1), 86 mm. S.L., UF 7228. 26°10′ N., 96°40′ W., *Oregon* station 1087 (1), 136 mm. S.L., TU 10643. Brownsville, Texas (1), 119 mm. S.L., USNM 171762. 23°36′ N., 87°54′ W., *Silver Bay* station 438, 68 fathoms, May 18, 1958 (3), 109–141 mm. S.L., BLBG.

DIAGNOSIS: No spinous dorsal fin. Dorsal soft rays 13 to 15. Anal soft rays 12 to 15. Pectoral rays 14 to 16. Pelvic rays I, 5, the spine obscured by skin. Pelvic girdle with paired anterior processes of conical spines protruding through the skin. Top of head covered by exposed cranial bones; a shallow anterior recess of the frontal bones between the eyes. Posterior nostrils not in fringed grooves. Lower jaw without a pair of prominent converging bony ridges. Preoperculum with three spines extending from ventral margin; operculum without a spine. Cleithral spine prominent, conical, sharply pointed, and extending posterodorsally. No scales present (scalelike structures present in lateral line). Lateral lines on each side of body extending from head along back close to dorsal fin, bending down to middle of caudal base, and ending between and nearly at ends of central caudal rays.

COLOR: Lower half of body whitish. Upper half of body with rounded white spots on brownish background, margins of the spots of darker brown, the spots confined mainly to predorsal area on small specimens, on large specimens the posterior spots larger and elongate. Pectoral fins with brownish black pigment across the fins. Pelvics clear. Anal fin with small area of pigment at posterior base. Dorsal fin with two to five and caudal fin with three or more blackish elongated spots, the spots more numerous in larger specimens.

SIZE: Largest specimen examined 204 mm. S.L. (about 10.2 inches T.L.). Smallest specimen examined 29 mm. S.L. A 21-mm. S.L. specimen is identified only to genus, because it lacks distinctive pigmentation and the pectoral fins are damaged.

RANGE: From Cape Lookout, N.C., to the Florida Keys and around the Gulf of Mexico to Campeche Bank off Yucatan. Depth records of all but one of the known specimens range from 22 to 100 fathoms, with the majority of these records between 30 and 60 fathoms. One specimen was recorded from 210 fathoms south of the Florida Keys where the Continental Shelf is very steep.

***Kathetostoma cubana* Barbour**

PLATE 3C-D

Kathetostoma albigutta cubana Barbour, 1941, p. 2 (type locality *Atlantis* station 3421 off the northern coast of Cuba. Holotype and 13 paratypes in Museum of Comparative Zoology, Nos. 35506, 35508, 35510, 35511, 35512, 35513, and 35514; 2 paratypes in U.S. National Museum, No. 153586; 2 paratypes sent to Museo Poey, Havana).

SPECIMENS EXAMINED

Kathetostoma cubana: 27°39′ N., 79°15′ W., *Silver Bay* station 441, 275–300 fathoms, June 9, 1958 (2), 67.5–119 mm. S.L., BLBG. 24°04′ N., 79°15′ W., *Combat* station 448, 250 fathoms, July 24, 1957 (1), 54.5 mm. S.L., BLBG. 24°04′ N., 79°15′ W., *Combat* station 448, 250 fathoms, July 24, 1957 (1), 55 mm.

S.L., USNM 159650. 22°50′ N., 79°08′ W., *Oregon* station 1344, 200–225 fathoms, July 16, 1955 (1), 66 mm. S.L., USNM 157986. 22°48′ N., 79°09′ W., *Atlantis* station 3422, 235 fathoms, Apr. 30, 1939 (3 paratypes), 86.5–118 mm. S.L., MCZ 35513. 22°50′ N., 78°55′ W., *Atlantis* station 3416, 200 fathoms, Apr. 30, 1939 (2 paratypes), 70.5–75 mm. S.L., USNM 153586. 16°39′ N., 81°43′ W., *Oregon* station 1878, 125 fathoms, Aug. 22, 1957 (1), 98 mm. S.L., UMML 4793. 16°39′ N., 82°29′ W., *Oregon* station 1870, 225 fathoms, Aug. 21, 1957 (1), 128 mm. S.L., TU 18848. 18°30′ N., 65°59′ W., *Oregon* station 2603, 230 fathoms, Sept. 25, 1959 (1), 85 mm. SL., USNM 195569.

Kathetostoma sp.: 27°49′ N., 84°12′ W., *Oregon* station 939, 35 fathoms, Mar. 18, 1934 (1), 21 mm. S.L., USNM 185674.

SYNONYMY: Barbour (1941, p. 1), apparently noting only color differences, described *K. cubana* as a subspecies of *K. albigutta*. Because of the consistent and discrete color differences, differences in pectoral ray counts and geographical and depth distribution, and differences in modal numbers of anal soft rays, we evaluate *K. cubana* as a distinct species.

DIAGNOSIS: No spinous dorsal fin. Dorsal soft rays 13 to 15. Anal soft rays 13 or 14. Pectoral rays 17 or 18. Pelvic rays I, 5, the spine obscured by skin. Pelvic girdle with paired anterior processes of conical spines protruding through the skin. Top of head covered by exposed cranial bones; a shallow anterior recess of the frontal bones between the eyes. Posterior nostrils not in fringed grooves. Lower jaw without a pair of prominent converging bony ridges. Preoperculum with three spines extending from ventral margin; operculum without a spine. Cleithral spine prominent, conical, sharply pointed, and extending posterodorsally. No scales present (scalelike structures present in lateral line). Lateral lines on each side of body extending from head along back close to dorsal fin, bending down to middle of caudal base, and ending between and nearly at ends of central caudal rays. Barbour (1941, p. 2) recorded fin counts as "usually with D. 11 and A. 11," but we have examined five paratypes and six other specimens in which the counts are consistently higher.

COLOR: Ventral part of body unpigmented, sides of body and head with faint pigment, dorsal surface of body and head mottled with irregular dull brown spots. Pelvic and anal fins unpigmented. Pectoral fins faintly pigmented. Dorsal fin faintly pigmented along the rays. Caudal fin with faintly pigmented spot on upper part of base and a broad darker blackish stripe located about middle of fin.

SIZE: Largest specimen reported about 146 mm. S.L. (7.75 inches T.L.). Smallest specimen examined 54.5 mm. S.L.

RANGE: Off the Little Bahama Banks, the Grand Bahama Banks, the northern coast of Cuba, off eastern Puerto Rico, and in the Caribbean off eastern Honduras. All the known specimens but one have been taken between depths of 180 and 300 fathoms; the other record was from 125 fathoms off Honduras. The type localities for *K. cubana* have not been published, and are furnished through the courtesy of Myvanwy M. Dick of the Museum of Comparative Zoology. They are all from off the north central coast of Cuba: *Atlantis* station 3392, 22°35′ N., 78°16′ W., 225 fathoms; *Atlantis* station 3396, 22°34′ N., 78°15′ W., 180 fathoms; *Atlantis* station 3414, 22°50′30″ N., 78°52′ W., 230 fathoms; *Atlantis* station 3416, 22°50′ N., 78°55′ W., 200 fathoms; *Atlantis* station 3421, 22°49′ N., 79°07′ W., 235 fathoms; *Atlantis* station 3422, 22°48′ N., 79°09′ W., 235 fathoms; *Atlantis* station 3423, 22°50′ N., 79°08′ W., 245 fathoms; *Atlantis* station 3437, 23°05′ N., 78°16′ W., 260 fathoms.

Genus *Gnathagnus* Gill

Gnathagnus Gill, 1861, p. 115. Type species: *Uranoscopus elongatus* Temminck and Schlegel, 1844, by monotypy.

Gnathagnus egregius (Jordan and Thompson)

Plate 4

Execestides egregius Jordan and Thompson, 1905, p. 253, figs. 5–6 (type locality reef at Garden Key, Tortugas, Fla. Type specimen in Stanford University Natural History Museum, SU 8411).—Longley and Hildebrand, 1940, P. 267 (reference), 1941, p. 244 (described after Jordan and Thompson, 1905).—Hildebrand, 1954, p. 318 ("24–10 grounds" off northern Gulf coast of Mexico, between 21 and 31 fathoms, specimen 87 mm. long).

Benthoscopus laticeps Longley and Hildebrand, 1940, p. 264, figs. 20–21 (type locality off Tortugas, Fla., between 90 and 175 fathoms; type specimen in U.S. National Museum, USNM 108879); 1941, p. 244 (reference).—Springer and Bullis, 1956, p. 97 (*Oregon* stations in the Gulf of Mexico).

Gnathagnus laticeps, Myers, 1946, p. 42 (generic relationship).

SPECIMENS EXAMINED

31°50′ N., 79°14′ W., *Combat* station 304, 180 fathoms, Apr. 22, 1957 (1), 197 mm. S.L., BLBG. 29°46′ N., 80°13′ W., *Combat* station 9, 200 fathoms, July 29, 1956 (1), 197 mm. S.L., GWM acct. Dinner Key, Biscayne Bay, Dade County, Fla., Mar. 1956, collector Fiefield (1), 57.5 mm. S.L., UMML 747. Off Tortugas, Fla., between 90 and 175 fathoms, collector Longley (holotype of *Benthoscopus laticeps*), 200 mm. S.L., USNM 108879. 24°20′ N., 83°20′ W., *Oregon* station 1005, 190 fathoms, Apr. 13, 1954 (2), 119–186 mm. S.L., GWM acct. 24°28′ N., 83°25′ W., *Oregon* station 1011, 200 fathoms, April 14, 1954 (1), 193 mm. S.L., CNHM 61325. 24°29′ N., 83°32′ W., *Oregon* station 1938, 200 fathoms, June 15, 1956 (1), 145 mm. S.L., TU 12716. 29°16′ N., 86°10′ W., *Oregon* station 1383, 125 fathoms, Sept. 7, 1955 (1), 113 mm. S.L., USNM 158823. 29°57′ N., 86°57.5′ W., *Oregon* station 326, 82 fathoms, Apr. 30, 1951 (1), 87 mm. S.L., GWM acct. No. 190888. 29°38′ N., 87°16.5′ W., *Oregon* station 281, 112 fathoms, Feb. 25, 1951 (1), 71.5 mm. S.L., CNHM 46648.

29°38′ N., 87°16.5′ W., *Oregon* station 281, 112 fathoms, Feb. 25, 1951 (1), 131 mm. S.L., GWM acct. No. 188434. 29°38′ N., 87°16.5′ W., *Oregon* station 281, 112 fathoms, Feb. 25, 1951 (1), 79 mm. S.L., USNM acct. No. 187053, GWM acct. No. 188434. 29°23′ N., 87°25′ W., *Oregon* station 270, 220 fathoms, Feb. 17, 1951 (1), 226 mm. S.L., GWM acct. No. 188434. 29°20′ N., 87°42′ W., *Oregon* station 265, 101 fathoms, Feb. 16, 1951 (1), 117 mm. S.L., CNHM 46650. 29°20′ N., 87°42′ W., *Oregon* station 265, 101 fathoms, Feb. 16, 1951 (1), 76 mm. S.L., CNHM 46649. 29°20′ N., 87°42′ W., *Oregon* station 265, 101 fathoms, Feb. 16, 1951 (1), 78.5 mm. S.L., GWM acct. No. 188434. 29°15.5′ N., 87°53′ W., *Oregon* station 314, 175 fathoms, Apr. 27, 1951 (1), 200 mm. S.L., GWM acct. No. 190888. 29°12′ N., 88°05′ W., *Oregon* station 637, 195 fathoms, Sept. 18, 1952 (1), 175 mm. S.L., TU 6834.

29°13.5′ N., 88°12′ W., *Oregon* station 2203, 125 fathoms, June 26, 1958 (5), 111–127 mm. S.L., BLBG. 29°03′ N., 88°25′ W., *Oregon* station 1107, 210–235 fathoms, June 15, 1954 (1), 175 mm. S.L., TU 12868. 28°57′ N., 88°40.5′ W., *Oregon* station 481, 210 fathoms, Sept. 7, 1951 (2), 211–229 mm. S.L., GWM acct. No. 190888. Between 29°05′ N., 88°31′ W., and 28°56.5′ N., 88°40′ W., *Oregon* stations 472 to 484, between 185 and 240 fathoms, Sept. 6–7, 1951 (2), 166–243 mm. S.L., CNHM 46651. 29°00′ N., 88°48′ W., *Oregon* station 93, 122 fathoms, Aug. 24, 1950 (1), 138 mm. S.L., GWM acct. No. 185983. 27°38′ N., 95°35′ W., *Oregon* station 1509, 225 fathoms, May 7, 1956 (1), 122 mm. S.L., TU 12807. 27°15′ N., 96°24′ W., *Pelican* station 112–1, 80 fathoms, Jan. 30, 1939 (1), 76.5 mm. S.L., GWM *Pelican* acct. No. 186572.

SYNONYMY: We adhere to Myers' (1946, p. 42) decision in placing *Benthoscopus laticeps* in the genus *Gnathagnus* Gill. We include *Execestides* Jordan and Thompson in the synonymy of *Gnathagnus*. The major recorded difference between *G. laticeps* and *Execestides egregius* was that the former had scales, the latter was scaleless. Our specimens of *Gnathagnus*, ranging from 243 mm. S.L. down to 57.5 mm. S.L., showed a pronounced structural ontogeny, and the presence of scales on all of these confirmed their identification as *G. laticeps*. George S. Myers, Margaret Storey, and Stanley H. Weitzman of the Stanford University Natural History Museum cooperated in furnishing us with information on the small type specimen of *E. egregius*, reported to lack scales. A portion of mucous scraped from the side near the peduncle of the type was stained with alizarin and a small scale was found to be present in the scrapings, presumptive evidence that the type specimen has small, hidden scales and supporting our placing *G. laticeps* in the synonymy of *E. egregius* in the genus *Gnathagnus*.

DIAGNOSIS: No spinous dorsal fin. Dorsal soft rays 12 to 14. Anal soft rays 16 or 17. Pectoral rays 20 to 24. Pelvic rays I, 5. Pelvic girdle without exposed anteriorly directed spines. Top of head covered by exposed cranial bones; a shallow anterior recess of the frontal bones between the eyes. Posterior nostrils not in fringed grooves. Lower jaw with the dentary bones forming a pair of prominent converging bony ridges on the anterior part, deeply notched between. Preoperculum with a flattened process, usually bluntly pointed, extending posteriolaterally from across angle of the bone, diminishing with growth; operculum striated and ridged and ending in a spine which diminishes with growth. Cleithral spine prominent, laterally compressed, and curved posteriodorsally. Scales present on body and extending onto fleshy part of caudal fin; scales absent on head, an area posterior to pectoral fin bases, the throat and abdomen, a small area posterior to the bones on top of the head, and a narrow area along the anal fin base; the scales small and deeply embedded in smaller specimens (the largest scale found on a 57.5-mm. specimen had a maximum diameter of 0.19 mm.). Lateral lines on each side of body extending from head along back close to dorsal fin, bending down to middle of caudal base, and ending between and nearly at ends of central caudal rays.

Color: At about 47 mm. S.L. (holotype description), body color blackish, fins pale with a blackish area at base of each, a pale streak along lateral line and one across base of dorsal. From 57.5 to 71.5 mm. S.L., head and dorsal half of body with irregular dark blotches tending to form broken stripes on back, scattered small pigment spots on rest of body, pelvics with spots at bases, other fins dark near bases. By 76 mm. S.L., head no longer dark spotted. By 87 mm. S.L., about the proximal three-fourths of the pectoral, dorsal, anal, and caudal fins are darkened, and the body has taken on a brownish cast. By 113 mm. S.L., the coloration of the upper half of the body consists of numerous small pigment spots, on some specimens these coalesce in some areas to form short lines.

Size: Largest specimen examined, 13 inches T.L. (243 mm. S.L.). Smallest specimen reported, 2⅛ inches total length (the holotype, about 47 mm. S.L.).

Range: All known specimens have been taken from off the coast of the United States: From off northern Georgia, eastern Florida, Tortugas and northwestern Florida, Alabama, Mississippi, and southern Texas. Of the specimens we examined, those larger than 100 mm. S.L. were taken from between about 101 and 240 fathoms; those from 71.5 to 100 mm. S.L. were taken from between 80 and 112 fathoms; and a 57.5-mm. S.L. specimen was taken at Dinner Key in Biscayne Bay, Florida. An 87-mm. T.L. specimen was reported from between 21 and 31 fathoms (Hildebrand, 1954, p. 318), and the 2⅛ inch holotype was taken "on the reef at Garden Key" (Jordan and Thompson, 1905, p. 254).

Literature Cited

ABBOTT, CHARLES C.

1861. Description of a new species of *Astroscopus*, Brev., in the Museum of the Academy of Natural Sciences of Philadelphia. Proc. Acad. Nat. Sci. Philadelphia, vol. 12 (1860), p. 365, pl. 7 [pp. 361 et seq. published in 1861, fide ANSP Index].

ANDERSON, WILLIAM W., and GEHRINGER, JACK W.

1957. Physical oceanographic, biological, and chemical data, south Atlantic coast of the United States, M/V *Theodore N. Gill* Cruise 4. U.S. Dep. Int., Fish Wildl. Serv., Spec. Sci. Rep., Fish., No. 234, pp. 192, figs. 19.

BAIRD, SPENCER F.

1884. On the specimens received by the Smithsonian Institution from the United States Life-Saving Service. Bull. U.S. Fish Comm., vol. 4, pp. 177–178.

BARBOUR, THOMAS

1941. A new Cuban star-gazer. Proc. New England Zool. Club, vol. 19, pp. 1–2.

BEAN, TARLETON H.

1879. On the species of *Astroscopus* of the eastern United States. Proc. U.S. Nat. Mus., vol. 2, pp. 57–63.

1892. Description of a new species of star-gazer (*Cathetostoma albigutta*), from the Gulf of Mexico. Proc. U.S. Nat. Mus., vol. 15, pp. 121–122.

BLOCH, M.E., and SCHNEIDER, J. GOTTLOB

1801. Systema ichthyologiae iconibus cx illustratum . . . . Berolini, pp. ix+584, pls. 110.

CUVIER, GEORGES, and VALENCIENNES, ACHILLE

1829. Histoire naturelle des poissons, Paris, F. G. Levrault, vol. 3, pp. xxviii+500, pls. 41–71.

1831. Histoire naturelle des poissons, Paris, F. G. Levrault, vol. 8, pp. xix+509, pls. 209–245.

DAHLGREN, ULRIC

1927. The life history of the fish *Astroscopus* (the "stargazer"). Scientific Monthly, vol. 24, April, pp. 348–365, figs. 1–11.

DEKAY, JAMES E.

1842. Zoology of New-York or the New York fauna, Albany, White and Visscher, pt. 1, Zool., pt. 4, Fishes, pp. xiv+415, pls. 79.

EVERMANN, BARTON W., and HILDEBRAND, SAMUEL F.

1910. On a collection of fishes from the Lower Potomac, the entrance of Chesapeake Bay, and from streams flowing into these waters. Proc. Biol. Soc. Washington, vol. 23, pp. 157–164.

EVERMANN, BARTON W., and KENDALL, WILLIAM C.

1900. Check-list of the fishes of Florida. Rep. U.S. Comm. Fish and Fish. (1899), pt. 25, pp. 35–103.

FOWLER, HENRY W.

1906. The fishes of New Jersey. Ann. Rep. New Jersey State Mus. (1905), pt. 2, pp. 35–477, text-figs., pls. 1–103.

1916. Records of northern New Jersey fishes. Copeia, No. 31, pp. 41–42.

1925. Records of fishes in New Jersey 1924. Copeia, No. 143, pp. 42–46.

1926. Records of fishes in New Jersey 1925. Copeia, No. 156, pp. 146–150.

1936. The marine fishes of West Africa. Bull. Amer. Mus. Nat. Hist., vol. 70, pt. 2, pp. 607–1493, figs. 276–567.

1941. A list of the fishes known from the coast of Brazil. Arq. Zool. Est. São Paulo, vol. 3, pp. 115–184.

1945. A study of the fishes of the southern Piedmont and coastal plain, Monogr. Acad. Nat. Sci. Philadelphia, No. 7, pp. 408.

1953. The shore fishes of the Colombian Caribbean. Caldasia, vol. 6, pp. 43–73.

GILL, THEODORE

1860. Notes on the nomenclature of North American fishes. Proc. Acad. Nat. Sci. Philadelphia, vol. 12, pp. 19–21.

1861a. Synopsis of the uranoscopids. Proc. Acad. Nat. Sci. Philadelphia, vol. 13 (1862), pp. 108–117.

1861b. Catalogue of the fishes of the eastern coast of North America, from Greenland to Georgia. Proc. Acad. Nat. Sci. Philadelphia, vol. 13 (1862), Appendix, pp. 63.

GREGORY, WILLIAM K.

1933. Fish skulls. A study of the evolution of natural mechanisms. Trans. Amer. Philos. Soc., vol. 23, pt. 2, pp. 75–481.

GÜNTHER, ALBERT

1860. Catalogue of the acanthopterygian fishes in the collection of the British Museum, London, Taylor and Francis, vol. 2, pp. xxi+548.

HILDEBRAND, HENRY H.

1954. A study of the fauna of the brown shrimp (*Penaeus aztecus* Ives) grounds in the western Gulf of Mexico. Pub. Inst. Mar. Sci., vol. 3, pp. 231–366, figs. 1–7.

HILDEBRAND, SAMUEL F., and SCHROEDER, WILLIAM C.

1928. Fishes of Chesapeake Bay. Bull. Bur. Fish., vol. 43 (1927), pt. 1, doc. 1024, pp. 366, figs. 211.

JORDAN, DAVID S.

1884. List of fishes collected at Key West, Florida, with notes and descriptions. Proc. U.S. Nat. Mus., vol. 7 (1885), pp. 103–150.

JORDAN, DAVID S., and EVERMANN, BARTON W.

1898–1900. The fishes of North and Middle America: A descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. U.S. Nat. Mus. Bull. 47, pt. 3, pp. xxiv+2183a–3136, 1898; pt. 4, pp. ci+3137–3313, pls. I–CCCXCII, 1900.

JORDAN, DAVID S., and GILBERT, CHARLES H.

1882. Synopsis of the fishes of North America. U.S. Nat. Mus. Bull. 16, pp. lvi+1018.

1883. Notes on a collection of fishes from Charleston, South Carolina, with descriptions of three new species. Proc. U.S. Nat. Mus., vol. 5, pp. 580–620.

JORDAN, DAVID S., and THOMPSON, JOSEPH C.

1905. The fish fauna of the Tortugas Archipelago. Bull. Bur. Fish., vol. 24 (1904), pp. 229–256, figs. 1–6.

JORDAN, DAVID S.; EVERMANN, BARTON W.; and CLARK, HOWARD W.

1930. Checklist of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. Rep. U.S. Comm. Fish. (1928), Appendix 10, pp. 670.

KIRSCH, PHILIP H.

1889. A review of the European and American Uranoscopidae or stargazers. Proc. Acad. Nat. Sci. Philadelphia, vol. 41, pp. 258–266.

LONGLEY, WILLIAM H., and HILDEBRAND, SAMUEL F.

1940. New genera and species of fishes from Tortugas, Florida. Carnegie Inst. Washington, Pub. 517, Pap. Tortugas Lab., vol. 32, pp. 223–285, figs. 28, pl. 1.

1941. Systematic catalogue of the fishes of Tortugas, Florida. Carnegie Inst. Washington, Pub. 535, Pap. Tortugas Lab., vol. 34, pp. xii+331, pls. 34.

MEEK, SETH E., and HILDEBRAND, SAMUEL F.

1928. The marine fishes of Panama. Field Mus. Nat. Hist., zool. ser., vol. 15, pt. 3, pp. xxv–xxxi+709–1045, pls. LXXII–CII.

MIRANDA RIBEIRO, ALIPIO DE.

1915. Fauna brasiliense. Peixes. V. [Eleutherobranchios aspirophoros] Physoclisti. Arch. Mus. Nac. Rio de Janeiro, vol. 17, 777 pp., illustrated [pages and plates not numbered consecutively].

MYERS, GEORGE S.

1946. Occurrence of uranoscopid fishes of the western Pacific genus *Gnathagnus* in the American Atlantic fauna. Copeia, No. 1, p. 42.

NICHOLS, J. T., and BREDER, C. M., JR.

1927. The marine fishes of New York and southern New England. Zoologica, vol. 9, pp. 192, figs. 261.

O'BRIEN, A. J.

1955. The stargazer. Nat. Hist., New York, vol. 64, pp. 90–93, illustrated.

PEARSON, JOHN C.

1941. The young of some marine fishes taken in lower Chesapeake Bay, Virginia, with special reference to the gray sea trout, *Cynoscion regalis* (Bloch). Fish. Bull. Fish Wildl. Serv., vol. 50, pp. 79–102, figs. 1–26.

SHUFELDT, R. W.

1901. Experiments in photography of live fishes. Bull. U.S. Fish Comm., vol. 19, pp. 1–5, pls. I–IX.

SMITH, HUGH M.

1907. The fishes of North Carolina. North Carolina Geol. and Econ. Surv., vol. 2, pp. xi+453, figs. 186, pls. 19.

SPIX, JOHANN B.

1831. Selecta genera et species piscium quos in itinere per brasiliam . . . Monachii, pp. 83–138, pls. XLIX–CI [publication date fide Dean, 1917, Bibl. Fish., vol. 2, p. 474].

SPRINGER, STEWART, and BULLIS, HARVEY R., JR.

1956. Collections by the *Oregon* in the Gulf of Mexico. U.S. Dep. Int., Fish Wildl. Serv., Spec. Sci. Rep., Fish., No. 196, pp. 134.

STEINDACHNER, F.

1876. Ichthyologishe beitrage. V. Sitzungsber. Akad. Wiss. Wien, vol. 74 (1877), 1 Abth., pp. 49–240, 15 pls. [not seen].

STORER, DAVID H.

1846. A synopsis of the fishes of North America. Mem. Amer. Acad., No. 7, pp. 298.

TEMMINCK, C., and SCHLEGEL, H.

1884. Pisces, *in* P. F. Siebold, Fauna Japonica, Tokyo, pp. 345, pls. 142 [1934 reprint].

Uhler, P. R., and Lugger, Otto
1876. List of fishes of Maryland. Rep. Comm. Fish. Maryland, pp. 67–176.

Weymouth, Frank W.
1910. Notes on a collection of fishes from Cameron, Louisiana. Proc. U.S. Nat. Mus., vol. 38, pp. 135–145, figs. 1–2.

White, E. Grace
1918. The origin of the electric organs in *Astroscopus guttatus*. Carnegie Inst. Washington, Pub. 252, Pap. Dep. Mar. Biol., vol. 12, pp. 139–172, fig. 1, pls. 1–7.

U.S. GOVERNMENT PRINTING OFFICE: 1961

Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 2, April, 1961
pp. 226–227

10

Effect of Tricaine Methanesulfonate on Oxygen Consumption of Juvenile Sockeye Salmon

The purpose of this study was to determine the feasibility of applying a constant-flow respirometer to the study of fish-behavior problems. The measurement of oxygen consumption of anesthetized and nonanesthetized juvenile sockeye salmon (*Oncorhynchus nerka*) was used as a test. The resulting data yielded information on the effects of tricaine methanesulfonate (M.S. 222—Sandoz), the anesthetic used, as well as demonstrated the effectiveness of the apparatus.

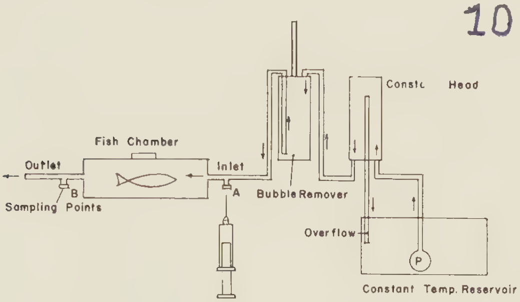


FIGURE 1.—Apparatus used to measure the oxygen consumption of small fish. At each end of the "fish chamber" are rubber diaphragms through which the water samples are drawn into a hypodermic syringe (points A and B). The difference in dissolved-oxygen content between inlet and outlet is the amount used by the fish.

The test fish were separated into two size classes: (1) "large" fish, 160–180 millimeters fork length; and (2) "small" fish, 60–80 millimeters fork length. Seven anesthetized large fish and seven not anesthetized were tested individually. The small fish were tested three to six at a time to achieve similar weight groups. Seven groups were anesthetized and seven groups were not anesthetized (Table 1).

The constant flow respirometer (Figure 1)

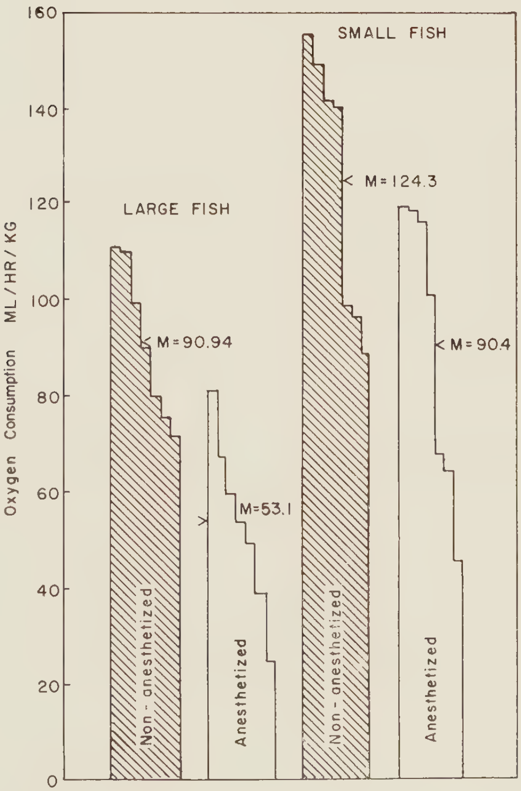


FIGURE 2.—Rate of oxygen consumption for two size classes of sockeye salmon fingerlings.

TABLE 1.—*Oxygen-consumption rates of two size groups of anesthetized and nonanesthetized juvenile sockeye salmon*

Large fish[1]				Small fish[2]			
Test number	Number of fish	Weight of sample (grams)	Consumption rate (ml/hr/gm)	Test number	Number of fish	Weight of sample (grams)	Consumption rate (ml/hr/gm)
			Anesthetized				
1	1	34	0.0810	8	6	25	0.1190
2	1	46	0.0670	9	6	29	0.1190
3	1	26	0.0590	10	6	31	0.1161
4	1	58	0.0535	11	4	18	0.1006
5	1	60	0.0495	12	6	48	0.0674
6	1	28	0.0383	13	6	25	0.0638
7	1	48	0.0238	14	4	19	0.0451
			Nonanesthetized				
1	1	35	0.1113	8	3	17	0.1560
2	1	37	0.1105	9	6	53	0.1492
3	1	47	0.0995	10	6	44	0.1408
4	1	47	0.0895	11	6	53	0.1403
5	1	56	0.0795	12	6	50	0.0984
6	1	30	0.0748	13	3	29	0.0969
7	1	58	0.0715	14	6	57	0.0887

[1] 160–180 millimeters fork length.
[2] 60–80 millimeters fork length.

was constructed from the description by Fromm (1958). The dissolved-oxygen content of the samples was determined by a modified Winkler method. All tests were conducted at a temperature of 14° C. The anesthetic was used at a concentration of 1:20,000.

The results not only showed the expected depression of the respiratory rates of the anesthetized fish (Baudin, 1932), but also indicated a uniformity of the drug's effect. It is obvious that the oxygen consumption per unit weight of the small fish is higher than that of the large fish (Figure 2). This difference is apparent not only before but after anesthetization. An analysis of variance showed no significant difference at the 5 percent level in the amount of respiratory depression between large and small fish regardless of the rate prior to anesthetization. This indicates that within this species the drug acts uniformly on fish of different sizes.

LITERATURE CITED

BAUDIN, LOUIS. 1932. Action de la tricaine sur la consommation d'oxygene de *Carassius auratus*. Compt. Rend. Hebdomadaires Soc. Biol., 109: 731–733.

FROMM, PAUL O. 1958. A method for measuring the oxygen consumption of fish. Prog. Fish-Cult., 20: 137–139.

T. H. BLAHM

Bureau of Commercial Fisheries
Biological Laboratory
Seattle, Washington

11

11

Made in the United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 1, January, 1961
pp. 21–26

Swimming Speed of Immature Atlantic Herring with Reference to the Passamaquoddy Tidal Project

H. C. BOYAR

Swimming Speed of Immature Atlantic Herring with Reference to the Passamaquoddy Tidal Project[1]

H. C. Boyar
U. S. Bureau of Commercial Fisheries, Biological Laboratory
Boothbay Harbor, Maine

ABSTRACT

To predict possible effects of the dams and gates of the proposed Passamaquoddy Tidal Power Project on herring movement in and out of the Passamaquoddy Bay region, information was first needed on the swimming performance of the fish. Maximum and sustained swimming speed tests designed for this purpose indicated (1) that the maximum swimming speed for herring 60 to 219 millimeters long ranged from 2.3 to 4.4 feet per second, and (2) that the swimming endurance (length of time a fish was able to swim in a particular water velocity) for herring of similar lengths exposed to water velocities of 1.2 to 3.2 feet per second ranged from 1 to 115 minutes. If the fish responds in the field as in the laboratory, the filling gates that operate at flood tide and emptying gates that operate at ebb tide would not appear to prevent migration.

INTRODUCTION

In the early fall of 1956 an investigation was begun to determine the possible effects the construction of dams in the Passamaquoddy Bay region, New Brunswick, Canada, would have upon the fisheries in the area. Of primary importance are the immature Atlantic herring (*Clupea harengus harengus* Linnaeus) which comprise approximately 85 percent of the total fish landings. Returns from 1957 and 1958 taggings suggest that these herring move in and out of Passamaquoddy Bay through either Letite or Western Passage, areas in which the surface water currents at times may reach a velocity of 10.0 feet per second (McKenzie and Skud, 1958; Skud and Boyar, 1958). With the possibility of even stronger currents being produced if the proposed Passamaquoddy Tidal Power Project dam and gates are constructed (Trites, personal correspondence), information was needed about the response of herring to currents of different velocities. To provide this information, studies of maximum and sustained swimming speed of immature herring were made at the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine. The maximum swimming speed study was concerned with the ability of a fish to maintain a position or actually swim against known water velocities over a 30-second period; the endurance study, with the length of time a fish could swim against a specific water velocity.

There is considerable published information on swimming speeds of fish. Many data have been obtained by timing fish movements in aquaria (Regnard, 1893), fishways (Stringham, 1924; R. L. Dow, personal correspondence), tanks (Lane, 1941), ponds (Davidson, 1949), culverts (Wales, 1950), and artificial channels (Ohlmer and Schwartzkopff, 1959). Recently, values for swimming speeds have been obtained principally by the use of a longitudinal, fixed trough (Kerr, 1953; Fields *et al.*, 1954[2]; Blaxter and Dickson, 1959) and by a circular, rotating trough (Fry and Hart, 1948; Radcliffe, 1950; Gray, 1957; Brett *et al.*, 1958; and Bainbridge, 1958). In the former, fish are subjected to different velocities of inflowing water against which they may or may not maintain their positions. In the circular, rotating trough (popularly known as the "fish wheel"), the water may be moved at varying speeds relative to the fish's visual field. In the present study, an attempt has been made to relate data on swimming speed from fish wheel experiments with field conditions.

MATERIALS AND METHODS

A circular tank (Figure 1), modified after Fry and Hart (1948) and Bainbridge and Brown (1958), was built to contain a trough with an outside diameter of 35¾ inches, a cross section of 5⅝ inches, and a depth of 6 inches. A 1-horse-power variable speed-reducer motor linked by a two-pulley belt system rotated the tank, and a graduated hand-wheel control varied the speed. Preliminary tests indicated that the apparatus could pro-

---

[1] International Passamaquoddy Fisheries Board, 1956–1959, Scientific Report No. 14.

[2] Fields, P. E., R. J. Adkins, and G. L. Finger. (1954) The swimming ability of immature silver salmon (*Oncorhynchus kisutch*) measured in an experimental flume. Univ. of Wash., School of Fish., Tech. Rept. 9, 22 pp. (Mimeo.)

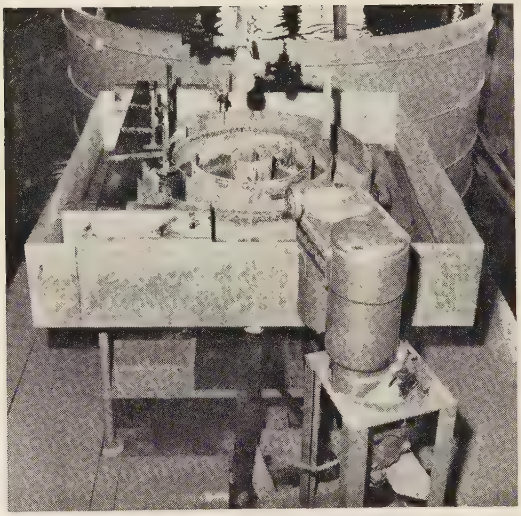


FIGURE 1.—Circular tank used in the swimming studies.

duce water velocities as high as 11 feet per second. Overhead jets supplied water to the trough; the rotation of the trough and a ¼-inch drain eliminated excess water.

Fish to be tested were placed in a specially designed stationary cage (25 inches long by 3¾ inches wide by 7 inches high, Figure 1) with wire mesh ends located in a section of the rotating trough. The cage permitted excellent observation of the fish's behavior and also eliminated visual reference points of the trough. A specially designed current meter (Boyar and Schueler, 1960) measured the water velocity in the cage.

Two types of experiments were conducted: (1) maximum swimming speed studies and (2) sustained swimming speed (endurance) studies. The maximum swimming speed was considered equivalent to the water velocity beyond which no individual could maintain its position for more than 30 seconds. The length of time a fish was able to maintain its position in a particular water velocity was considered its sustained swimming speed. In the first test, fish in the cage were subjected to a water velocity in which they swam steadily. The water velocity was then increased gradually. When the fish was pinned against the rear screen of the cage, its maximum swimming speed was considered to be reached. In the endurance studies, fish were subjected to specific water velocities and made to maintain their position until pinned against the cage's rear screen. On occasion, a gentle prod with a glass rod induced the fish to leave the screen and swim forward. If the fish failed to leave the screen after 15 seconds, the test was considered completed.

Herring to be tested were held in a live-car (Boyar and Sindermann, 1959), and appeared to be in good condition, differing in weight from wild fish of equivalent length by not more than 1 gram. Fish from 60 to 219 millimeters long, weighing from 2 to 65 grams, were used. Temperatures during the maximum swimming speed studies were from 1.4° to 5.6° C., and 9.5° to 11.2° C.; and in the sustained swimming speed studies from 1.4° to 5.6° C.

RESULTS

Rheotaxis tests

Circular tank experiments are conducted on the premise that fish provided with a fixed visual reference point will swim in a direction opposite to the movement of the tank, in a manner similar to their behavior in a stream. In a stream, the current tends to force the fish downstream, and in the tank, backward. In either case, the fish opposes the movement of water and swims, exerting enough energy to keep its same visual field. Lyon (1904) and Keenleyside and Hoar (1954) reported that when a fish swam against a current, it did so in response to (1) visual, (2) tactile, or (3) labyrinthine reflexes. This assumption infers that the fish had to see or feel some fixed object in its environment, or somehow experience the currents over the bottom surfaces, before it would orient against the current.

Prior to making herring swimming speed studies, it was necessary to determine whether positive rheotaxis would occur in this species. One hundred and thirteen fish from 65 to 200 millimeters long were tested in water velocities ranging from 0.5 to 3.0 feet per second (Table 1). Since at the time of this study there was no published report of their responses to various water velocities, it was decided that if they oriented opposite to the water flow within 20 seconds of exposure, the herring were positively rheotactic.

TABLE 1.—*Percentage of herring oriented against various water velocities at the end of 20 seconds*

Number of fish	Range of length (millimeters)	Water velocity in feet per second				
		<0.7	0.7	1.5	2.2	3.0
27	65–99	98	100	100	—	—
29	100–134	94	100	100	—	—
36	135–169	86	95	100	100	—
21	170–200	82	90	100	100	100

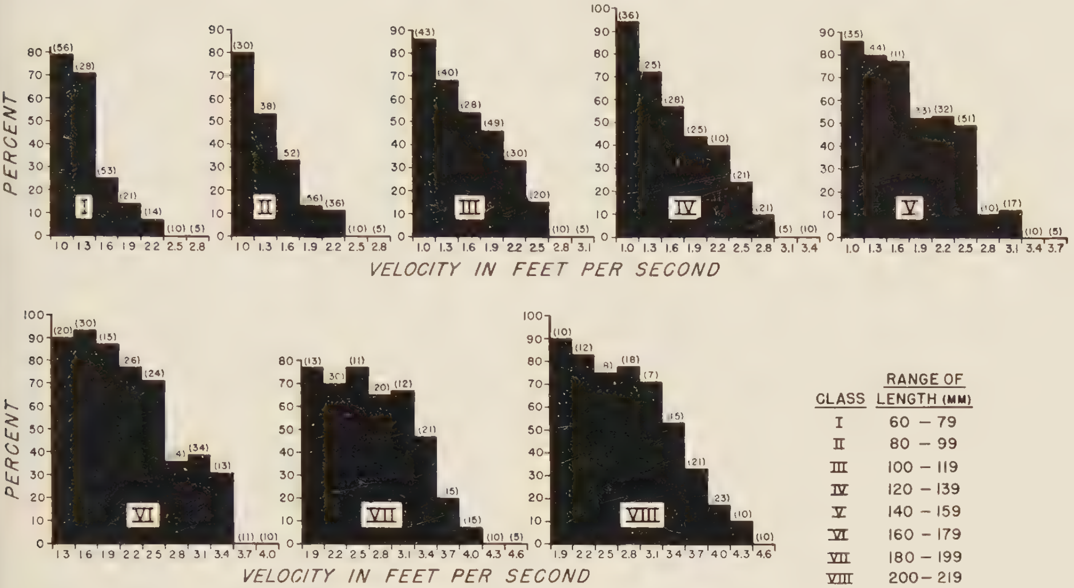


FIGURE 2.—Percentage of herring able to maintain position for 30 seconds against various water velocities (number of fish tested in parentheses).

Fish failed to respond positively only at speeds of 0.7 foot per second or less, and these fish were larger than 134 millimeters. The results indicated that herring, under the conditions of the experiment, will orient against various water movements, and that this response is dependent upon the fish's size and the water velocity.

Maximum swimming speed tests

The results of maximum swimming speed tests with 1,551 herring from 60 to 219 millimeters long are shown in Figure 2. Fish have been divided into eight length classes, each with a range of 20 millimeters. The water velocities vary from 0.9 to 4.7 feet per second and the data have been grouped by 0.3-foot-per-second intervals.

There appears to be a direct relationship between swimming speed and body length of the fish, *i.e.*, the longer the fish, the greater the percentage of individuals able to swim in a particular current. In addition, there is indication that increase in water velocity resulted in a decrease in the percentage of fish of a particular class to swim at this velocity. A herring's maximum swimming speed was considered to be the maximum velocity at which fish could swim over a 30-second period. Because there were relatively few tests conducted at this limit, additional tests at the next higher speed (increase of 0.3 foot per second) were made for all length classes and served as confirmation. The critical velocity has been arbitrarily designated as the water velocity at which 60 percent or more of the fish of a particular class were unable to swim. The maximum swimming speeds and the critical velocities are shown in Figure 2.

The difference between the maximum swimming speed and the mean critical velocity of any class ranged from 0.4 to 0.7 foot per second.

Sustained swimming speed tests

The swimming endurance of 215 herring from 68 to 205 millimeters long was determined for water velocities from 1.2 to 3.2 feet per second. The results obtained are shown in Table 2. Rectification of the nonlinear data was found to depend on a log-log transformation and could be illustrated by a linear graph, log of endurance in minutes (E) plotted against log of length in millimeters (L). This indicates that endurance is a function of approximately the fourth power of length (Table 3, column 3). The length-endurance curves plotted from these calculated functions are shown in Figure 3, while the results of the linear regression analysis are shown in Table 3. K and i are the values for the slope and y-intercept of the regression line;

Table 2.—*Relationship between length (L) in millimeters and actual endurance (E) in minutes of herring exposed to various water velocities*

Water velocities in feet per second																	
1.2		1.4		1.7		2.0		2.3		2.6		2.8		3.0		3.2	
L	*E*	*L*	*E*	*L*	*E*	*L*	*E*	*L*	*E*	*L*	*E*	*L*	*E*	*L*	*E*	*L*	*E*
68	1	69	1	74	1	88	1	81	1	104	1	118	1	134	5	129	2
72	2	79	4	77	2	99	1	94	1	111	1	128	2	140	1	135	2
78	2	81	2	78	2	103	4	98	2	118	2	134	2	148	2	141	1
82	5	85	3	80	4	109	14	105	3	122	2	136	3	149	3	143	2
84	3	87	3	81	1	114	7	109	11	129	3	137	4	152	2	147	3
90	8	92	2	89	2	114	19	113	5	132	4	138	5	154	2	152	3
90	8	93	13	91	4	119	13	118	6	137	4	139	5	158	1	159	2
92	7	94	8	93	2	122	8	124	5	137	5	142	13	159	6	163	8
92	26	99	11	101	14	123	16	132	11	143	1	144	4	163	2	168	4
95	13	105	9	105	11	123	14	136	8	147	2	144	11	168	2	172	4
102	14	107	13	108	7	126	15	140	9	151	17	147	3	176	3	174	2
106	13	109	19	116	14	128	11	146	16	155	41	156	5	182	5	179	4
107	20	113	12	122	11	130	21	150	9	157	10	160	9	189	7	185	5
108	19	116	22	128	17	133	16	153	12	167	18	165	5			201	7
111	18	118	17	132	20	137	10	155	16	168	14	172	3			203	13
114	23	123	21	134	22	146	14	156	14	172	14	173	13			205	17
131	32	127	19	137	18	147	28	159	19	172	16	174	4				
133	41	129	26	140	19	148	39	163	22	176	18	178	16				
139	40	132	23	142	54	149	19	168	29	179	24	184	9				
143	63	134	31	144	66	150	12	170	34	184	29	184	18				
152	82	137	48	145	42	151	14	174	38			188	14				
157	120	142	39	145	52	152	12	178	41			189	14				
		143	20	149	49	160	23										
		147	26	154	59	162	34										
		150	150	156	65	165	21										
		154	132	156	48	171	33										
				159	68	176	39										
				162	80	177	45										
				166	73												

n, the number of fish tested; S.E., the standard error of the estimate; *r*, the value of the correlation coefficient; and *t*, the variate testing significance of the slope. Significant values at the 1 percent level for *r* and *t* have been obtained for velocities of 1.2 to 2.8 feet per second. At a velocity of 3.0 no significant values for either *r* or *t* were obtained, while at a velocity of 3.2 a significant value for *t* and not *r* was obtained.

From the analysis it appears that the herring's swimming endurance is dependent upon its length and the water velocity. As the velocity increased, swimming endurance for a particular length class decreased. As the fish's size increased, its swimming endurance at a particular water velocity increased.

The slopes for the swimming endurance of fish exposed to velocities of 1.4 and 1.7, 2.0 and 2.3, 2.6 and 2.8, and 3.0 and 3.2 are similar. The maximum difference of endurance between these curves was 15 minutes for fish tested in velocities of 1.4 and 1.7, 10 for fish tested in velocities of 2.0 and 2.3, 6 for fish tested in velocities of 2.6 and 2.8, and 3 for fish tested in velocities of 3.0 and 3.2. Because of this similarity, the fish tested were regrouped into larger classes (Table 4).

Table 3.—*Statistical analysis of the length–endurance relationship of herring exposed to various currents* ($X = \log L$, $Y = \log E$)

Velocity (feet per second)	*n*	Regression line $Y = KX + i$	S.E.	*t*	*r*
1.2	22	$Y = 4.9825X + (-8.9111)$	0.1659	14.30*	0.9545*
1.4	26	$Y = 4.3393X + (-7.7063)$	0.3285	6.82*	0.7362*
1.7	29	$Y = 4.3269X + (-7.8268)$	0.2176	13.16*	0.8792*
2.0	28	$Y = 4.1561X + (-7.7131)$	0.2343	7.23*	0.8170*
2.3	22	$Y = 4.5268X + (-8.6657)$	0.4930	12.87*	0.9445*
2.6	20	$Y = 4.7345X + (-9.4505)$	0.3712	4.56*	0.7327*
2.8	22	$Y = 4.0135X + (-8.0363)$	0.2407	4.76*	0.7285*
3.0	13	$Y = 2.4956X + (-5.0697)$	0.8276	1.43	0.3967
3.2	16	$Y = 4.2215X + (-8.7879)$	0.6347	5.17*	0.2563

*Significant at the 1 percent level

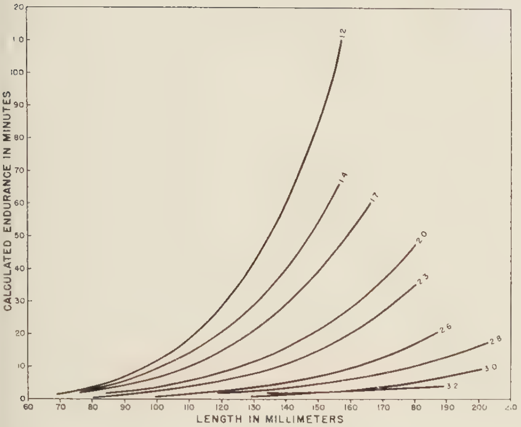


FIGURE 3.—Calculated length endurance relationship of herring exposed to various currents. (Figures at extreme end of curves represent water velocity in feet per second.)

It can be seen in the table that only fish greater than 139 millimeters would be able to swim as long as 30 minutes; this would be possible only at velocities less than 2.0 feet per second.

DISCUSSION

In recent years, water power developments have been partially responsible for studies on the swimming speed of fish. Of primary interest have been the investigations concerned with the ability of fish to swim through gates or up proposed fishways. Most of the values obtained have been for fresh-water or anadromous fish. In a situation such as the Passamaquoddy Power Project, the marine fish (in this case herring) are of primary importance. Information on herring was needed to evaluate effects of proposed structures.

In the present study, the maximum swimming speed was found to range from 2.3 to 4.4 feet per second for fish from 60 to 219 millimeters. This range agrees quite closely with the 1.8 to 4.4 feet per second found by Blaxter and Dickson (1959) for European herring of comparable length. The ratio of maximum speed to length ranged from 6 to 9, or slightly less than the 10 proposed by Gray (1957) as a general ratio for the maximum speed of small fresh-water fish. The ability of the fish to exert a sudden burst of speed has been postulated by Gray to be of more importance than the maintenance of cruising speed. This assumption is undoubtedly true in situations where a darting movement is needed to catch prey, escape predators, or for other reasons. The importance of this sudden burst of speed, however, is of less concern than cruising speed in a situation where fish must swim at a steady rate. Cruising speed has been defined by Fry and Hart (1948) as "that speed at which the fish could swim steadily for some period of time, although presumably after hours fatigue would set in." In the past, this method was satisfactory to obtain values for a fish's swimming performance at a particular current speed. In the present study, sustained speed (endurance) tests at a number of velocities were made and are proposed as the best means of obtaining endurance-length values. Herring exposed to water velocities of 1.2 to 3.2 feet per second gave endurances ranging from 1 to 115 minutes. The results of the tests appear to be the first complete series of this type. Although temperature would probably have an effect on swimming endurance, its effect was not tested in the present study.

TABLE 4.—*Average swimming endurance of herring (in minutes) against various water velocities*

Range of length (millimeters)	Water velocity in feet per second								
	1.2	1.4	1.7	2.0	2.3	2.6	2.8	3.0	3.2
<99– 99	6	4	3	2	1	0			
100–139	28	22	16	9	6	3	2	1	1
140–179	89	50	42	28	22	11	7	2	3
180–219						19	13	4	8

If the proposed dams and gates are constructed across Passamaquoddy Bay, it is apparent that herring entering the bay through the passages could do so only at times when the filling gates were open. Since this period will be only 3 out of 12½ hours, the time of access to the bay by this route would be reduced considerably. If herring enter primarily at flood tide at present, no drastic reduction in fish immigration should occur if the dams and gates are constructed. The closure of the gates during ebb tide will prevent any fish's leaving the bay through the passage, while the flood tide would be too strong for it to swim against. As a result herring could enter but not leave the bay through the passage. The same conditions would also apply to Western Passage where the filling gates are designed to open and close at the same time as those of Letite Passage and where water velocities would be similar. Herring could enter but not leave.

The question remains as to whether herring could enter the bay region through the emptying gates. Since water velocity outward through these would be approximately the same as that of the inflow through the filling gates (Trites, personal correspondence), any massive immigration would be unlikely. Although the emptying gates would be open 3½ hours out of 12½, fish entering the bay by this route could do so only when the water velocity was less than 2.0 feet per second, a period of less than 20 minutes every 24 hours.

ACKNOWLEDGMENTS

I wish to thank Dr. C. J. Sindermann, Mr. L. W. Scattergood, and Mr. A. P. Stickney of the Bureau of Commercial Fisheries Research Laboratory at Boothbay Harbor, Maine, for their valuable suggestions in the preparation of this manuscript. I also wish to thank Mr. B. E. Skud of the Bureau of Commercial Fisheries Research Laboratory at Galveston, Texas, who participated in the experiment's original design.

LITERATURE CITED

Bainbridge, R. 1958. The speed of swimming of fish as related to size and to the frequency and amplitude of the tail beat. Jour. Exp. Biol., 35: 109–133.

Bainbridge, R., and R. H. J. Brown. 1958. An apparatus for the study of the locomotion of fish. Jour. Exp. Biol., 35: 134–137.

Blaxter, J. H. S., and W. Dickson. 1959. Observations on the swimming speeds of fish. Jour. du Conseil, 24: 472–479.

Boyar, H. C., and F. E. Schueler. 1960. A photoelectric current meter. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. 330, 7 pp.

Boyar, H. C., and C. J. Sindermann. 1959. Additional notes on the maintenance of immature sea herring in captivity. Prog. Fish-Cult., 21: 185–187.

Brett, J. R., M. Hollands, and D. F. Alderdice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. Jour. Fish. Res. Bd. Canada, 15: 587–605.

Davidson, Viola. 1949. Salmon and eel movement in constant circular current. Jour. Fish. Res. Bd. Canada, 7: 432–448.

Fry, F. E. J., and J. S. Hart. 1948. Cruising speed of goldfish in relation to water temperature. Jour. Fish. Res. Bd. Canada, 7: 169–175.

Gray, J. 1957. How fishes swim. Sci. Amer., 197: 48–54.

Keenleyside, M. H. A., and W. S. Hoar. 1954. Effects of temperature on the responses of young salmon to water currents. Behaviour, 7 (2–3): 77–87.

Kerr, J. E. 1953. Studies on fish preservation at the Contra Costra stream plant of the Pacific Gas and Electric Company. Calif. Fish. Bull. 92, 66 pp.

Lane, F. W. 1941. How fast do fish swim? Country Life, London, Sept.: 534–535.

Lyon, E. P. 1904. Rheotropism in fishes. Jour. Physiol., 12 (2): 149–161.

McKenzie, R. A., and B. E. Skud. 1958. Herring migrations in the Passamaquoddy region. Jour. Fish. Res. Bd. Canada, 15: 1329–1343.

Ohlmer, W., and J. Schwartzkopff. 1959. Schwimmgeschwindigkeiten von Fischen auf stehenden Binnengewässern, 46 (10): 362–363.

Radcliffe, R. W. 1950. The effect of fin-clipping on the cruising speed of goldfish and coho salmon fry. Jour. Fish. Res. Bd. Canada, 8: 67–73.

Regnard, P. 1893. Sur un dispositif qui permet de measurer la vitesse de translation d'un poisson se mouvant dans l'eau. Compt. Rend. Soc. Biol., Paris, Ser. 9 (5): 81–83.

Skud, B. E., and H. C. Boyar. 1958. Sardine sized herring tagged in coastal waters. Maine Coast Fisherman, 13 (1): 28.

Stringham, E. 1924. The maximum speed of freshwater fishes. Amer. Nat., 58: 156–161.

Wales, J. H. 1950. Swimming speed of the western sucker *Catostomus occidentalis* Ayes. Calif. Fish and Game, 36: 433–434.

12

12

Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 4, October, 1961
pp. 404–412

Recoveries of Tagged, Hatchery-Reared Lake Trout from Lake Superior

HOWARD J. BUETTNER

Recoveries of Tagged, Hatchery-Reared Lake Trout from Lake Superior

HOWARD J. BUETTNER
U. S. Bureau of Commercial Fisheries, Biological Laboratory, Ann Arbor, Michigan

ABSTRACT

Plantings that totaled 13,384 tagged, hatchery-reared lake trout (*Salvelinus namaycush*)—18, 25, 30, or 37 months old—were made at four Lake Superior localities in 1955–57 to: measure possible increases of return from rearing to greater size and age; study the effect of season of planting on the rate of return; compare returns from different types of tags; and follow the movements of hatchery-reared fish. The great advantage of spring over fall planting, demonstrated for fingerling lake trout in earlier experiments, did not hold for fish planted at ages of 18 to 37 months. The improvement of recovery rates with increase of age over the same 18- to 37-month interval appears to be too small to justify the cost of rearing to the higher ages. The recovery rates were closely similar (3.9 to 4.8 percent) for lower-jaw tags and two types of nylon-streamer tags but were much lower than the rate for Petersen tags (12.4 percent). The pins of Petersen tags render the fish highly vulnerable to entanglement in the webbing of gill nets, the principal gear in Lake Superior. Recoveries of Petersen tags also came earlier after planting than did those of other tags. The time between planting and recovery and the distance traveled by the fish were clearly but not closely correlated. Mean distance between points of planting and recovery increased with time out, and average time out increased with the number of miles traveled. More than half of the recoveries of fish that had been at liberty over 2 years were made within 25 miles of the point of release.

INTRODUCTION

From 1951 to 1958 the production of lake trout (*Salvelinus namaycush*) in the commercial fisheries of the United States waters of Lake Superior decreased an average of 265,000 pounds per year. In 1957 the catch had fallen to 1,190,600 pounds. This was the seventh time since 1879, the earliest year of record, that the yield was less than 2 million pounds. In 1958 the production declined still more to 1,059,700 pounds, an all-time low. A take of 3 million pounds per year is considered average for the more recent period of this fishery (Hile, Eschmeyer, and Lunger, 1951). These declines in landings have accompanied the increase in abundance of the parasitic sea lamprey. It appears that the fate of the lake trout in Lake Superior will parallel that in Lakes Huron and Michigan until control of the lamprey is effected.

Prospects for reduction of sea lamprey stocks now appear to be good. After the sea lamprey is brought under control, a program of restocking the upper Great Lakes will have to be carried out. Before this action is taken, it is desirable to gain more knowledge on the best age and season for planting hatchery-reared lake trout to obtain the maximum survival.

The earliest and most extensive experimental studies of returns from hatchery-reared lake trout were based on fingerling and yearling fish (age-groups O and I) that had been marked by the removal of fins. The Wisconsin Conservation Department has made extensive plantings of fin-clipped fingerling and yearling lake trout in Lake Superior. In 1952–58 they fin-clipped 1,191,300 hatchery-reared lake trout, releasing them in both the fall and spring. Their report at the annual meeting of the Great Lakes Fishery Committee for 1955[1] stated: ". . . spring planting of lake trout appears to be more desirable than fall planting in the Apostle Island Area of Lake Superior," and in 1958 they reported: "Since 1955, a total of 4,211 recoveries have been reported; . . . 3,609, or 89.5 percent have been spring-planted fish. . . ."

The Bureau of Commercial Fisheries started a similar experiment in 1952 and by 1958 had fin-clipped and planted 888,400 fingerling lake trout in Lake Superior. In their 1955 report to the Great Lakes Fishery Committee they stated: ". . . A total of 91 fin-clipped lake trout had been recovered. . . . Of these, 85 had been planted in the spring and only 6 had been stocked in the fall." Reporting to this Committee in 1957, they stated: "Returns indicate conclusively that survival is the better from spring plantings."

The program of tagging the larger hatchery-reared lake trout, begun by the Bureau of Commercial Fisheries in 1955 (with Paul H. Eschmeyer as project leader) and continued through 1957, was an extension of this earlier

---

[1] Minutes of all meetings of this Committee (now the Upper Great Lakes Fishery Committee) have been issued in processed form.

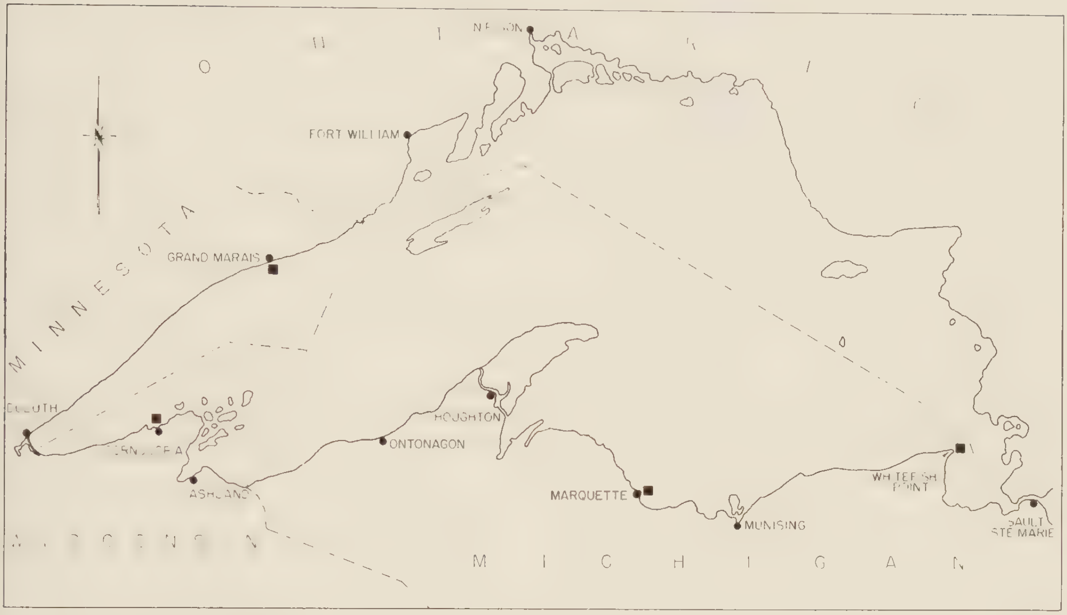


FIGURE 1.—Planting localities (black squares) for tagged, hatchery-reared lake trout released in Lake Superior.

work. We wished to learn whether the seasonal differences that held for the smaller lake trout extended to fish of larger sizes and greater ages, to gain some knowledge as to whether holding trout in hatcheries a longer period of time would give greater survival in the lake, to determine how fish move after planting at different ages and seasons, and to test differences among the several tags with respect to the rate of recapture and growth of the trout. The present report is concerned with recovery of trout of different ages and year classes marked with the different tags and planted in different seasons. It deals also with the relation between time out and distance traveled before recapture.

Reports of recoveries began to fall off sharply in the spring of 1959, and the project was terminated on September 30, 1959. The last group of fish planted, therefore, was free approximately 2 years and 4 months. As few returns could be anticipated after this period, the records can be considered essentially complete for all plantings. The majority of recoveries (74 percent) were reported within the first year, and recaptures after 2 years of freedom were low. The actual time at liberty for the different lots up to the end of the experiment ranges from 1,452 days (4.0 years) for fish planted in October 1955 to 875 days (2.4 years) for those planted in May 1957.[2]

MATERIALS AND METHODS

The 1954 and 1955 year classes[3] of lake trout were used in this experiment. The 1954 year class came from eggs taken in Lake Superior off Marquette, Michigan, and Munising, Michigan, and the 1955 class from eggs taken in western Lake Superior off the Bad River. The 1954 year class suffered heavy mortality from "blue sac" and " white spot" diseases. These fish were hatched at the Marquette State Fish Hatchery. They were moved to the Lake Mills Federal Station as advanced sac fry and were reared there until April 1955. They were then transferred to the Pendills Creek Fish-Cultural Station located on Whitefish Bay, in eastern Lake Superior. The 1955 year class was hatched at the Lake Mills Federal Station and reared there until the fish were transferred to Pendills Creek in July 1955. These fish suffered only normal mortality. While at Pendills Creek, both lots of fish received the same care and feed and experienced only normal mortality.

Fish hatched in 1954 were tagged and released in October 1955 at an age of 18 months,

---

[2] Based on midpoint of planting period. For the various sets of releases it took as many as 16 days to plant all of the fish.

[3] The lake trout spawns in the fall, but the eggs hatch the following spring. Year classes are dated by year of hatching.

TABLE 1.—*Number of lake trout tagged and released by tag type, age, year class, and locality of planting*

Date planted and type of tag	Year class and age (months)	Number planted					Length at planting (inches)	
		Grand Marais, Minnesota	Cornucopia, Wisconsin	Marquette, Michigan	Whitefish Point, Michigan	Total	Average	Range
October 1955	1954							
Petersen		137	200	199	200	736	8.4	7.5–10.0
No. 34 streamer	18	178	200	198	200	776	8.4	7.0–10.4
No. 46 streamer		167	198	199	198	762	8.4	7.5–10.2
Lower jaw		183	200	200	200	783	8.4	7.5–10.5
Total		665	798	796	798	3,057	8.4	7.0–10.5
October 1956	1955							
Petersen		198	194	200	196	788	8.5	7.1–10.5
No. 34 streamer	18	99	96	99	96	390	8.4	6.9–10.6
No. 46 streamer		99	97	100	98	394	8.4	7.0–10.3
Lower jaw		200	200	200	200	800	8.4	6.9–11.1
Total		596	587	599	590	2,372	8.4	6.9–11.1
October 1956	1954							
Petersen		100	94	100	100	394	11.9	7.9–14.6
No. 34 streamer	30	50	49	47	49	195	12.0	9.4–14.5
No. 46 streamer		48	50	49	50	197	11.9	8.8–14 6
Lower jaw		99	96	100	100	395	11.9	8.4–15.0
Total		297	289	296	299	1,181	11.9	7.9–15.0
May 1956	1954							
Petersen		197	200	200	200	797	10.0	7.5–12.8
No. 34 streamer	25	201	200	200	197	798	10.1	8.0–12.8
No. 46 streamer		199	201	199	200	799	10.1	8.2–12.5
Lower jaw		200	200	201	200	801	10.0	7.8–12.4
Total		797	801	800	797	3,195	10.0	7.5–12.8
May 1957	1955							
Petersen		198	198	199	200	795	9.8	7.7–14.0
No. 34 streamer	25	99	97	99	100	395	9.9	7.7–12.5
No. 46 streamer		98	98	100	97	393	9.9	7.6–15.4
Lower jaw		200	199	199	200	798	9.8	7.4–12.8
Total		595	592	597	597	2,381	9.8	7.4–15.4
May 1957	1954							
Petersen		100	99	100	100	399	13.7	8.8–17.3
No. 34 streamer	37	49	50	50	50	199	13.7	8.2–17.1
No. 46 streamer		49	50	50	50	199	13.8	8.6–17.2
Lower jaw		101	100	100	100	401	14.0	8.7–17.5
Total		299	299	300	300	1,198	13.8	8.2–17.5
Grand total, average, or range		3,249	3,366	3,388	3,381	13,384	9.8	6.9–17.5

in May 1956 at 25 months, in October 1956 at 30 months, and in May 1957 at 37 months. Fish of the 1955 year class were tagged and released in October 1956 at an age of 18 months, and in May 1957 at 25 months. All tagging took place at Pendills Creek. Fish were anesthetized with tricaine-methanesulfonate.

Portions of each planting were marked with four types of tags (Table 1—see Figure 1 for planting localities): Petersen; streamer tag—No. 34 "Nylock" gill-net twine (tensile strength, 4.5 pounds) with a yellow plastic disc; streamer tag—No. 46 "Nylock" gill-net twine (tensile strength, 6 pounds) also with a disc; and lower jaw. On only two occasions were streamer tags attached by No. 34 and No. 46 thread treated as separate marks (October 1955 and May 1956 releases). On the remaining four the combined lots of streamer tags equalled approximately the numbers marked by Petersen or jaw tags. The Petersen and both types of streamer tags were attached to the fish through the back just posterior to the dorsal fin. These three types of tags carried a serial number and letter; the jaw tag bore a number only. All carried the letters "USFWS" on the reverse side. Each fish was measured before tagging. The numbers of fish released with each type of tag were similar at the four localities on each planting date (Table 1), with the exception of the October 1955 plant off Grand Marais, Minnesota, when high mortality reduced the number stocked.

A form letter was sent to all United States commercial fishermen on Lake Superior explaining the project, describing the various types of tags, and requesting their cooperation in reporting recoveries. In addition, each fisherman was sent an addressed post card to facilitate the reporting. The card asked for information on tag number, date of capture, length at capture, location, and depth of water from which the nets were lifted. New post cards were sent to the fishermen with each acknowledgment of reports received. As returns were received, the records were transferred to IBM cards. All tables were prepared from IBM tabulations of these records.

No reward was offered for the return of the tags. Most reports were sent directly to the Biological Laboratory in Ann Arbor, but some were handled by the Bureau's staffs at Marquette, Michigan, and Ashland, Wisconsin. Returns were also forwarded to the laboratory by A. J. Herridge and J. W. Lockwood, Ontario Department of Lands and Forests; Ben Gustafson, Minnesota Department of Conservation; Russell Daly, Wisconsin Conservation Department; and Leland Anderson, Michigan Department of Conservation.

Leonard S. Joeris, Joseph Beil, Gaylord Anderson, and Willis S. Glidden assisted in the tagging. The cooperation of the many commercial fishermen who reported recoveries and of those who assisted in the plantings is greatly appreciated. G. A. Drake, Superintendent of the Pendills Creek Fish-Cultural Station, was in charge of the stocking. The figures were drafted by William Cristanelli. Ralph Hile advised in the analysis of data and in the preparation of the manuscript.

RECOVERIES FROM DIFFERENT PLANTING LOCALITIES

Although nearly equal plantings were made off each port, the distribution of recoveries of tagged lake trout varied considerably. The number and percentage of recoveries from each port was:

Port of planting	Number of recoveries	Percentage of total recoveries
Cornucopia, Wisconsin	309	34
Marquette, Michigan	306	34
Grand Marais, Minnesota	176	19
Whitefish Point, Michigan	117	13
Total	908	—

Circumstances favored a good rate of return at Cornucopia. Biologists of the Wisconsin Conservation Department have had close association with Wisconsin fishermen for many years, and in 1957 the Bureau of Commercial Fisheries established a research station at Ashland. Furthermore, the local fishery has continued to be fairly productive. Wisconsin's annual lake trout catch averaged over ½ million pounds in 1929–56; in 1957 and 1958, however, production dropped below 300,000 pounds.

Several factors account for the numerous recaptures at Marquette. The Marquette–Munising area has always been a major contributor to the lake trout production of Michigan waters of Lake Superior (1929–43 average of 18.7 percent). The Bureau has had a field station at Marquette since 1950 and has maintained close contact with the commercial fishermen in the general area. Even though catches from this area have declined, fishing intensity has continued at a substantial level to recent years.

Rapidly declining fishing pressure and the widely scattered fishing operations along the North Shore probably account in part for relatively poor returns from the Grand Marais, Minnesota, plantings. It was reported that some fishermen in this area were annoyed by the use of the Petersen tag because it occasionally became badly tangled in the netting and forced them to cut their twine to release the fish. It is suspected that returns from this area might have been greater if the fishermen had been more willing to cooperate.

Relatively light fishing intensity was surely a factor in the low number of recoveries in the Whitefish Point area. A moderate percentage of the few fishermen in this region do a considerable amount of fishing for whitefish and lake herring. Of the 117 reports from this area, 53 came from Canadian fishermen.

The recoveries from the four planting areas showed similar trends with respect to relative rate of return of the different types of tags and lots of fish, distribution of the recoveries in time, and distance of the movements of fish. For all future consideration, therefore, the data for these localities have been pooled.

RECOVERIES BY TYPE OF TAG

A total of 908 or 6.8 percent of the 13,384 trout tagged were recovered (Table 2). The recovery rate for the 3,909 lake trout released with Petersen tags was 12.4 percent, the highest of any of the four tags used. Recoveries of other types of tags were: 4.5 percent of the 2,753 No. 34 streamer; 3.9 percent of the

TABLE 2.—*Recoveries of lake trout tagged with various types of tags*

[Age groups, planting seasons, and localities combined]

Type of tag	Number tagged	Recoveries	
		Number	Percentage
Petersen	3,909	486	12.4
No. 34 streamer	2,753	125	4.5
No. 46 streamer	2,744	108	3.9
Lower jaw	3,978	189	4.8
All types	13,384	908	6.8
All types except Petersen	9,475	422	4.5

2,744 No. 46 streamer; and 4.8 percent of the 3,978 jaw tags.

The differences among the three "non-Petersen" tags are probably not significant. The numbers recovered were few (125 for the No. 34 streamer, 108 for the No. 46 streamer, and 189 for the lower-jaw tags), and records of returns according to age or season of planting revealed considerable variability in the rate of recovery of each type. Data for these three types of tags were therefore combined.

The advantage of Petersen tags over other types can be judged from the ratio of the percentages of recovery (Table 3). The rate of return of Petersen tags was 2.6 times as great as that of streamer and jaw tags combined for the 1954 year class and 2.7 for the 1955 year class. The advantage of Petersen tags decreased consistently with increase of age at planting.

The recovery rate of the Petersen-type tags was high apparently because this tag becomes easily entangled in the mesh of gill nets. Thus the fish are highly vulnerable to capture as the wire pin tangles in the webbing, regardless of fish size or mesh size. The fish bearing the other three types of tags did not become entangled so easily and hence were taken readily only in nets of appropriate mesh.

RECOVERIES BY AGE GROUP, YEAR CLASS, AND SEASON OF PLANTING

Accurate interpretation of records of recovery by age and year class requires knowledge of the general level of fishing to which each group was exposed following planting. Large annual changes in fishing intensity could place different plantings under widely different pressures and thus influence greatly their expectation of recapture. The only gears that contributed significantly to the capture of tagged lake trout in the present experiment were large-mesh trout gill nets (4½ inches or greater, extension measure) and small-mesh chub (deep-water ciscoes—*Coregonus* spp.) gill nets 2¼ to 2¾ inches and 3 inches permitted in Michigan in water not deeper than 100 feet). The minimum mesh size for trout nets is 4½ inches in all three states. The minimum mesh for chub gill nets is 2¼ inches in Minnesota, 2⅜ inches in Wisconsin, and 2½ inches in Michigan.

The relative effectiveness of trout and chub gill nets in capturing the tagged lake trout was not determined. For fish marked with Petersen tags, mesh size probably has little bearing on the chance of capture since most fish are caught by the tangling of the pin in the webbing of the nets. Lake trout marked with other types of tags should be taken more readily in chub nets than in trout nets while they are small. As the fish grow larger they become less vulnerable to chub nets and more vulnerable to trout nets. Legal-sized trout (17 inches or longer) are taken in chub nets and undersized trout can be numerous in trout nets. The best estimate of fishing pressure against the tagged lake trout in any single year is probably the total amount of gill nets fished for lake trout and for chubs.

Fishing intensity of trout and chub gill nets in the United States waters of Lake Superior (Table 4) was closely similar in 1955 and 1956 and among the 3 years 1957–59, but the difference of level between the two periods was considerable. The average total lift for 1955–56 was 1.34 times that for 1957–59. This shift from a higher to a lower level of exploitation tends to bias returns upward for fish planted at the younger ages and also to bias the records toward higher returns for the 1954 than for the 1955 year class.

Members of the 1954 year class, planted at 18 months in October 1955 (Table 3) were subjected 7 months longer to the higher fishing level of 1955–56 than were fish planted

TABLE 3.—*Percentage recoveries for lake trout marked with Petersen and three other tag types by year class and age*

Year class and age at planting (months)	Date of planting	Percentage recovered		Ratio of Petersen to others	Average percentage
		Petersen	Others[1]		
1954					
18	October 1955	14.9	3.2	4.7	9.0
25	May 1956	16.2	5.8	2.8	11.0
30	October 1956	17.5	7.5	2.3	12.5
37	May 1957	14.8	7.9	1.9	11.4
Average		15.8[2]	6.1[2]	2.6	11.0[2]
1955					
18	October 1956	6.6	1.8	3.7	4.2
25	May 1957	8.4	3.7	2.3	6.0
Average		7.5[2]	2.8[2]	2.7	5.1[2]

[1] See Table 2.

[2] Unweighted mean.

TABLE 4.—*Intensity of the gill-net fisheries for lake trout and chubs in the United States waters of Lake Superior, 1955–59*

[Unit is 10,000 linear feet of gill net]

Year	Number of units lifted		
	Lake trout	Chubs	Total
1955	14,729	1,159	15,888
1956	13,747	1,357	15,104
1957	10,143	1,796	11,939
1958	8,397	3,130	11,527
1959	7,395	3,731	11,126

at 25 months in May 1956, and both of these age groups were fished more heavily than the 30-month-old fish planted in October 1956 and the 37-month trout planted in May 1957. Lake trout of the 1955 year class planted at 18 months in October 1956 probably were fished at a slightly higher rate than the 25-month-old fish planted in May 1957.

Comparisons of 1954 and 1955 year-class fish of the same age are limited to lake trout planted at 18 and 25 months. The 18-month-old lake trout of the 1954 year class were exploited a full year longer at the higher 1955–56 rate than were members of the 1955 year class planted at the same age. The 25-month fish of the 1954 year class planted in May 1956 were exploited at the high rate the remainder of that year whereas all fishing for 1955 year-class trout planted in May 1957 was at the lower 1957–59 level.

It is not practical to attempt the correction of data to eliminate the effects of the change in the level of exploitation, but interpretations of comparative records of recoveries of age groups and year classes must be conditioned by the knowledge that the change did occur.

The percentage recoveries for the lake trout of the 1954 year class marked with Petersen tags (Table 3) increased slightly with age from the 18-month-old through the 30-month-old fish but fell off for the 37-month-old fish. The percentage recoveries for fish released with the other three tag types increased with age from 18-month- through 37-month-old fish. For all types combined, recoveries increased from 18 to 30 months and decreased at 37 months (but still exceeded the percentage for 25 months). Of the two age groups of the 1955 year class planted, the older (25 months) had higher returns than the younger ones (18 months) for both types of tags. It can be concluded, therefore, that in general the returns tended to be the greater among fish planted at the higher ages. The advantage of the older over the younger fish in percentage of recapture would have been greater (especially in the 1954 year class) if fishing pressure had been as high in 1957–59 as in 1955–56. Even so, the improvement almost surely would be much too small to justify the cost of building the holding facilities and of rearing the fish to the higher ages—at least within the age range of these experiments.

The rates of recovery from plantings of the 1954 year class far exceeded those of the 1955 year class for fish planted at 18 and 25 months —the only ages at which members of both year classes were stocked (Table 5). The advantage of the 1954 year class as indicated by the ratio of its percentage return to the percentage for the 1955 year class varied with age and type of tag. For both types of tags the advantage of the 1954 year class was greater for fish planted at 18 months than for those planted at 25 months, and for both age groups the advantage of the 1954 year class was greater with Petersen tags than with tags of other types. In general, members of the 1954 year class were returned at a rate about twice that of the 1955 year class. Because of bias from change in the rate of exploitation as previously detailed, we cannot accept the ratio of 2.0 (both age groups, all types of tags) as accurately descriptive of the survival advantage of the 1954 over the 1955 year class. The records of the extent of the change of fishing pressure and of the time each age group was exposed to the higher 1955–56 intensity make it possible, nevertheless, to state with confidence that the survival of the 1954 year class was at least 1.5 times that of the 1955 year class. The cause of the difference between the year classes is not known, but it may be significant that the higher recovery rates were from the year class that suffered heavy mortality in the hatchery. Conceivably this mor-

TABLE 5.—*Comparison of percentage recoveries of tagged lake trout of the 1954 and 1955 year classes*

Year class	Age (months)	Date of planting	Percentage recoveries		
			Petersen	Other	Average
1954	18	October 1955	14.9	3.2	9.0
1955	18	October 1956	6.6	1.8	4.2
Ratio of percentages			2.3	1.8	2.1
1954	25	May 1956	16.2	5.8	11.0
1955	25	May 1957	8.4	3.7	6.0
Ratio of percentages			1.9	1.6	1.8
1954	18, 25	See above	15.6	4.5	10.0
1955	18, 25	See above	7.5	2.8	5.1
Ratio of percentages			2.1	1.6	2.0

tality weeded out the weaker members of this group.

The great advantage of spring over fall plants of fin-clipped fingerlings and yearlings with respect to rate of recapture does not extend to tagged fish planted at greater ages. The interpretation of comparisons of spring and fall plants (Table 3) is complicated by the trend toward increase of recoveries with increase of age at planting and by the change in the level of fishing pressure from 1955–56 to 1957–59. The general conclusion is warranted, however, that any advantage of spring over fall plantings that may exist in older fish is relatively unimportant.

TIME BETWEEN PLANTING AND RECOVERY

Detailed tabulations failed to disclose any trend with age or differences between year classes in the percentage distribution of the total recoveries among the time intervals following planting. Any bias that may have been introduced by the shift in fishing pressure seemingly was obscured by the large differences between the data for different types of tags and seasons of planting. These two factors did influence strongly the percentages of the total number of recoveries obtained in the subsequent periods of time (Table 6, Figure 2). In general, the differences between tags were much greater than the differences between seasons.

A high percentage (69.0 percent) of all recoveries of lake trout bearing Petersen tags and planted in May was returned during the first 3 months. The cumulative percentage of total recaptures had increased to 89.4 percent at the end of 12 months and stood at 97.6 percent at the end of 24 months. Recapture of fish marked with the same tag but planted in October proceeded relatively slowly during the first 6 months (cumulative percentages of 42.9 and 56.3 at 3 and 6 months as compared to 69.0 and 79.2 percent for lake trout planted in May). The percentages for the two groups were closely similar, however, at 9 months and later. Differences between the returns from May and October plantings during the first 6 months were largely the result of seasonal dif-

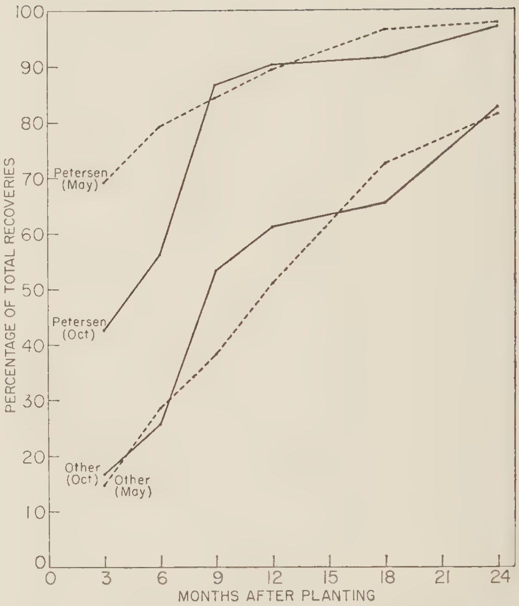


FIGURE 2.—Cumulative percentage of total recoveries of tagged, hatchery-reared lake trout planted in Lake Superior according to type of tag and season of planting.

TABLE 6.—*Distribution of recoveries of tagged lake trout through selected time intervals following planting*

[Months are based uniformly on 30 days each]

Tag, month of planting, and item of data	Months after planting							Total recoveries
	<3	3–5	6–8	9–11	12–17	18–23	>23	
Petersen (May)								
Number recovered in period	176	26	13	13	18	3	6	255
Percentage of total recoveries	69.0	10.2	5.1	5.1	7.0	1.2	2.4	—
Cumulative percentage	69.0	79.2	84.3	89.4	96.4	97.6	100.0	—
Petersen (October)								
Number recovered in period	99	31	70	8	3	13	7	231
Percentage of total recoveries	42.9	13.4	30.3	3.5	1.3	5.6	3.0	—
Cumulative percentage	42.9	56.3	86.6	90.1	91.4	97.0	100.0	—
Other types (May)								
Number recovered in period	38	37	25	33	55	23	49	260
Percentage of total recoveries	14.6	14.2	9.6	12.7	21.2	8.9	18.8	—
Cumulative percentage	14.6	28.8	38.4	51.1	72.3	81.2	100.0	—
Other types (October)								
Number recovered in period	27	15	44	13	7	28	28	162
Percentage of total recoveries	16.7	9.2	27.2	8.0	4.3	17.3	17.3	—
Cumulative percentage	16.7	25.9	53.1	61.1	65.4	82.7	100.0	—

ferences in fishing pressure. The amount of fishing during the 6 months following October varies annually according to weather conditions but is far less than the fishing in the 6 months following May.

Lake trout marked by other tags (streamer and jaw tags) were difficult to capture during the first 6 months after stocking, since fewer than 30 percent of the total recoveries of fish planted in the spring and fall had been made by the end of that period. Contrary to the situation with the Petersen tags, the early recoveries of fish planted in May and October were much the same. The cumulative percentages were much higher for October than for May plantings at the end of 9 and 12 months, but the return for the May stocking was higher at 18 months. The percentages for the two groups were nearly the same at the end of 24 months when somewhat more than 80 percent (May, 81.2 percent; October, 82.7 percent) of total recoveries had been made. The temporary separation of the curves at 9 and 12 months can be ascribed to differences of fishing pressure exerted against the two groups. During their second 6 months of liberty lake trout of the October plantings were in a period of heavy summer fishing. The second 6 months in the lake for May plantings fell in the winter period of limited fishing.

In these experiments the early returns came in rapidly from fish marked with Petersen tags but slowly from those tagged with other types. Most of the recoveries of Petersen tags were within 12 months (about 90 percent of all recoveries) and only 3 percent or fewer of the total recoveries were made after 2 years. The streamer and jaw tags were returned in substantial numbers during the second year of liberty, and approximately 18 percent of the total recoveries were made after 2 years.

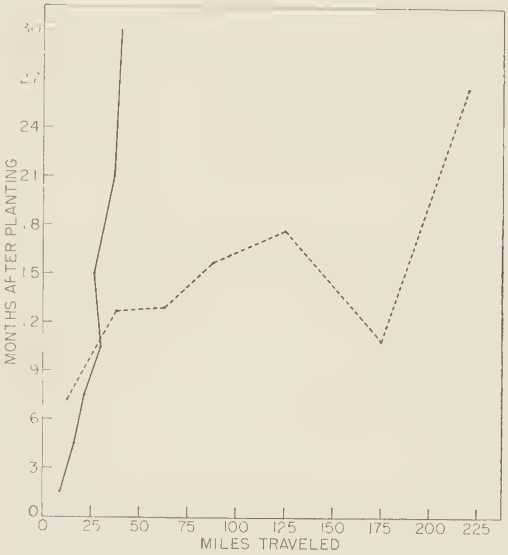


FIGURE 3.—Relation between time out and distance traveled by tagged, hatchery-reared lake trout in Lake Superior. Solid line, mean distance traveled by fish grouped according to time out; broken line, mean time out for fish grouped according to distance traveled.

RELATION BETWEEN TIME OUT AND DISTANCE TRAVELED

Although the timing of the recoveries differed sharply according to type of tag and season of planting, there were no differences in distance traveled other than those attributable to differences in the length of time at liberty. The data for all plantings were combined, therefore, for the preparation of Table 7 and Figure 3.

The period at liberty and the distance between points of planting and recapture were clearly but not closely correlated. None of the 340 lake trout captured within 3 months after planting had moved more than 75 miles

TABLE 7.—*Recoveries of tagged lake trout, all types of tags combined, expressed by distance traveled and time out*

Miles traveled	Time out (months)							Total	Percentage	Average time out (months)
	<3	3–5	6–8	9–11	12–17	18–23	>23			
< 26	306	94	105	37	50	35	52	679	74.8	7.2
26– 50	24	8	36	19	23	23	19	152	16.7	12.7
51– 75	10	3	6	4	3	4	8	38	4.2	12.9
76–100	—	1	3	3	1	1	4	13	1.4	15.7
101–150	—	—	1	3	2	1	2	9	1.0	17.7
151–200	—	2	1	1	2	1	—	7	0.8	11.0
>200	—	1	—	—	1	3	5	10	1.1	26.3
Total	340	109	152	67	82	68	90	908	—	—
Percentage	37.5	12.0	16.7	7.4	9.0	7.5	9.9	—	—	—
Average distance	9	16	21	30	26	37	40	—	—	—

and most of them (306) were taken within 25 miles. The mean distance for the group was 9 miles. As time out increased, more fish were captured at greater distances but the increase of mean distance was so slow (small decrease at 12–17 months) that the average amounted to only 40 miles for trout at liberty 2 years and more.

Similarly, the increase of average time out for lake trout recovered at successively greater distances was relatively slow and not perfectly regular. The mean period of liberty was shortest (7.2 months) for fish caught within 25 miles of the point of release. It rose steadily with increase of distance to 17.7 months at 101–150 miles but decreased to 11.0 months at 151–200 miles. Ten fish caught over 200 miles from the planting locality, however, had an average time out of more than 2 years, and only one was recaptured in less than 1 year.

The poor correlation between time out and distance traveled resulted from the strong tendency of fish to remain near the point of release regardless of the length of time they had to scatter to other areas. Even among fish that had been free more than 2 years, the majority (52 of 90) were recovered within 25 miles of the planting locality. The relation between time out and movement of these tagged, hatchery-reared lake trout planted in Lake Superior resembled closely that for small native lake trout (average length, about 12 inches) tagged in Lake Michigan (Smith and Van Oosten, 1940).

LITERATURE CITED

Hile, Ralph, Paul H. Eschmeyer, and George F. Lunger. 1951. Status of the lake trout fishery in Lake Superior. Trans. Am. Fish. Soc., 80: 278–312.

Smith, Oliver H., and John Van Oosten. 1940. Tagging experiments with lake trout, whitefish, and other species of fish from Lake Michigan. Trans. Am. Fish. Soc., 69: 63–84.

13

Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Thirteenth Annual Session, November, 1960
Pages 168-171

Effects of Pesticides on Commercial Fisheries

Philip A. Butler
Bureau of Commercial Fisheries
Gulf Breeze, Florida

The need for an extensive and continuing research program to determine the effects of agricultural chemicals on our fish and wildlife resources has been apparent for many years. The ever-increasing amount and variety of these chemicals in use on farms and forests have made the problem one of national concern. More recently, the need for comprehensive studies in the estuarine environment has been recognized, and various agencies have initiated limited investigations in this area. Much of the research done in the past has demonstrated that these chemicals may be highly selective in their toxicity even to closely related forms. Although they have been developed primarily for their toxic effects on particular groups such as insects, rodents, or weeds, some have had unexpected and disastrous effects on associated biota. Their effects may vary widely in different environments depending on meteorological conditions such as wind and rain. The character of the soil, and in aquatic habitats the water chemistry and types of sediments, may greatly influence their toxicity.

Knowledge of these variables alone makes it highly desirable that thorough studies be conducted in our estuarine habitats where more than thirty of our most important commercial species of fish, shellfish and crustacea spend a part or all of their lives.

There are other and more compelling reasons why intensive investigations of this type of chemical pollution are needed to protect our fishery resources.

Despite the fact that a majority of the pesticides are only sparingly soluble, it is inevitable that sooner or later significant amounts of them will collect in our rivers and estuaries, either as particulate matter, adsorbed on silts and detritus or perhaps in some new chemical relationship.

It must be noted that many of these chemicals are in use today because of their specific toxicity to arthropods. Yet it is an arthropod, the shrimp, our most valuable commercial species, which utilizes estuaries as its nursery grounds. In this same group, of course, are both kinds of lobsters, the blue crab and the stone crab, all of considerable economic importance.

It is a matter for especial concern that marine bottom forms including clams and oysters may be unusually susceptible to these chemicals. They may be poisoned by them, or what could be more serious, they may concentrate these poisons in their digestive organs and other body tissues. Unfortunately it is just these forms which we use whole and frequently unprocessed as food. The analogy here to the situation in which birds were poisoned indirectly by eating earthworms that had concentrated pesticides in their tissues is both appropriate and threatening.

There have been accidental but dramatic instances in which extensive mortalities occurred to fish and crab populations in different areas as a result of insect control programs. Such incidents are, however, the exception and our real problem concerns the immediate and long range effects of pesticides reaching estuarine areas indirectly.

At present, we do not know how much or what pesticides are being transported from farm and forest lands through drainage basins into the estuaries. We have no dependable qualitative and quantitative tests for identifying them when highly diluted in the marine environment. We do not know if degradation products of these pesticides, formed in transit, are more or less lethal to marine fauna than the parent chemical. Nor do we have much information on the cumulative effects of sub-lethal concentrations. The possibility of synergistic effects with other environmental components is an untouched field for investigations.

The fluid medium of the estuarine environment makes it much more possible for harmful combinations or sequences of events to take place than in terrestrial applications of these chemicals. Consequently, it is difficult to predict from laboratory testing programs the end results of field applications. There are inherent difficulties in maintaining most of the commercial species of fish and shellfish for long periods under laboratory conditions.

For these reasons, much of our initial effort has been devoted to relatively rough screening programs of the most important pesticides and to the development of appropriate bio-assay techniques.

During the past fiscal year, Bureau of Commercial Fisheries laboratories have made considerable progress on the overall problem. Examination of the accumulated data has been discouraging, not because of a lack of results, but because they demonstrate the complexity of the problems with which we are faced.

Some of these results I should like to review briefly and indicate their possible implications.

The Biological Laboratory at Milford, Connecticut, because of its excellent technical facilities and experience, has concentrated its efforts on studies of phytoplankton and molluscan larvae in relation to pesticides. Their studies have shown the extraordinary toxicity of some of the herbicides to the unicellular phytoplankton utilized by molluscan larvae as food. One of these, lignasan, was highly toxic at concentrations of only a few parts per billion. The other herbicides tested were toxic at much less than one part per million and this was true for many of the insecticides as well. It is obvious what disastrous effects relatively small quantities of such chemicals could have in upsetting the food web in a restricted estuary.

Of equal concern are their findings that many of the most common insecticides have a strongly toxic effect on oyster and clam larvae. Relatively high concentrations, up to 1 ppm, were required to cause significant mortality, but at lower concentrations, growth rates were invariably decreased.

The Galveston Biological Laboratory has conducted an insecticide screening program with emphasis on commercial species of shrimp. Their data show that all of these chemicals are extremely toxic to shrimp, causing 50 per cent mortalities at concentrations of less than 50 parts per billion. Equally disturbing is their finding that the same chemical may have entirely different toxic values when formulated with different so-called inert carriers. For although there are only 200 or so basic chemicals in use today, the number of formulations runs into the thousands.

The Biological Laboratory at Gulf Breeze, because of special facilities for evaluating the activity of oysters, has concentrated its efforts on, first, a screening program to determine the toxicity to oysters of the common pesticides, and, second, to the development of better techniques of bio-assay.

In working with oysters, the concept of LD_{50}, or the concentration of a poison causing a 50 per cent mortality in a given length of time, has little meaning. If oysters don't like their environment they close their valves and effectively remove themselves. Consequently, in our testing programs it is necessary to use concentrations of the pesticide sufficiently dilute to prevent the oyster from closing.

Initially, pesticide toxicity was evaluated by determining the number of hours per day test animals were open and presumably feeding. Continuous kymograph recordings were made of their shell movements in order to measure their activity. Under these conditions, it was found that their activity might appear to be unaffected for days or even weeks at a given concentration of a chemical before adverse changes could be detected. As a double check on the value of activity data, records were maintained on weekly growth increments of young oysters kept in the same aquaria. It was soon found that not only were growth increments equally reliable, but there was no time lag in the appearance of adverse effects as shown by decreased growth rates. A logical sequence to these results was to discover how long a time interval was needed to establish changes in growth rates. Obviously, tests requiring four to six weeks for conclusive results, as in the shell activity work, are of limited value in a program faced with testing hundreds of chemicals.

We have now standardized our methods for using the growth rate of young oysters as an index of chemical pollution and they merit a brief description here. Small oysters from 1-1½ inches in length are used since they grow in all months of the year in contrast to larger oysters in our area. The posterior or open end of the valves is filed with a rasp until all of the membranous or soft new shell growth is removed. The removal of this shell does not harm the tissues of the oyster which contracts internally when it is handled. With moderate care there is no danger of actually making an opening into the shell cavity. Control and experimental groups are then placed in suitable containers of circulated untreated and treated sea water. Measurements of shell deposition are made at convenient intervals, usually daily for three days, using an ocular micrometer with low magnification. Records are maintained on the growth increments of the oysters individually.

We find that only 10 oysters are required to provide data for a statistically valid sample. Within a wide range of hydrographic conditions, control oysters will deposit approximately one mm of new shell growth per 24 hours. Since a control group is used, there is no necessity for maintaining constant salinity and temperature levels. One day's observations are normally sufficient to determine the required range of concentrations to be tested and three day tests provide definitive results.

Obviously this technique can not be applied to work with mature fish and crustacea but perhaps it is applicable to larval forms which grow fast enough so that changes in rate of growth may be quickly observed.

Both the Milford and Gulf Breeze workers have noted that the first evidence of toxicity of pesticides to shellfish is a decrease in growth rates. It is reasonable to suggest that our ability to evaluate this item may eliminate much costly and time-consuming work in the future. We are interested not only in the pollution levels causing acute toxicity and death, but also those causing more subtle reactions which over a period of time may affect reproductive potential and longevity.

Using the growth of small oysters as a criterion of pesticide toxicity, we find two points of particular interest. After the lowest concentration of a chemical that causes a decrease in growth has been determined, we find that exposure to a further ten-fold dilution produces no apparent ill effects, even over a period of several weeks. Secondly, when adversely affected oysters are returned to clean sea water, the normal growth rate is reinstated within a short period of time, usually a few days.

We may hope that so far as oysters are concerned, and perhaps other estuarine forms, that not only are subacute toxicities transitory but that they may be avoided by relatively small increases in the dilution factor. It is possible that under natural conditions, and barring accidents, average dilution factors are so great that these chemicals pose no real threat to estuarine and marine forms.

These items are not suggested to lull us into any feeling of security with regard to chemical pollution but rather to point out how a coordinated and productive research program can provide the basis for better resource management. Agricultural chemicals are here to stay. With sufficient knowledge of their immediate and residual effects, it will be possible for us to utilize them to the fullest extent and with minimum damage to our valuable natural resources both on land and in the sea.

14

POPULATIONS OF THE BUTTERFISH, *PORONOTUS TRIACANTHUS* (PECK), WITH SYSTEMATIC COMMENTS[1]

David K. Caldwell[2]
U. S. Bureau of Commercial Fisheries Biological Laboratory
Brunswick, Georgia

Reprinted from the
BULLETIN OF THE SOUTHERN CALIFORNIA ACADEMY OF SCIENCES
1961, Vol. 60, Part 1, pp. 19-31
Los Angeles, California

shifting to any considerable degree of the intestinal tract. It may be added that the intestine penetrates the heart.

The gonads of specimens of *S. patula* taken in early June contain fully developed eggs; those collected in late summer evidently had passed the breeding season. In this last named collection the reproductive gland presents essentially the same appearance as in the case of individuals of *S. sloati* dredged in the month of August. It therefore is difficult to determine whether this last named species is represented by adult individuals. No sections were made of the gonad or kidney of either species, and their relations to each other are unknown.

The pericordial cavity is single, no dorsal or ventral septum being present. The general position of the organ is represented on Plate 6, Fig. 9.

POPULATIONS OF THE BUTTERFISH, *PORONOTUS TRIACANTHUS* (PECK), WITH SYSTEMATIC COMMENTS[1]

DAVID K. CALDWELL[2]
U. S. Bureau of Commercial Fisheries Biological Laboratory
Brunswick, Georgia

ABSTRACT

Examination of large series of butterfish from throughout their range revealed three major populations: a deep-bodied form in the Gulf of Mexico; an intermediate form in Western Atlantic waters of 12 fathoms or less south of Cape Hatteras; and a generally shallow-bodied form in Western Atlantic waters north of Hatteras and south of Hatteras beyond 13 fathoms. *Peprilus burti* Fowler is placed in the synonymy of *Poronotus triacanthus* (Peck).

INTRODUCTION

The butterfish, *Poronotus triacanthus* (Peck), a fish of the family Stromateidae, constitutes an important human food and sport resource in parts of its range, particularly in New England waters (Bigelow and Schroeder, 1953: 367) and the mid-Atlantic states (Hildebrand and Schroeder, 1928: 215). This species also finds many uses as a commercial scrap fish in various processed forms and as crab bait and fertilizer — in addition to being, through its large numbers, a valuable forage species.

---

[1] Contribution No. 56, U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

[2] Also a Collaborator, Florida State Museum, and Collaborator in Ichthyology, Institute of Jamaica. Present address: Los Angeles County Museum, Los Angeles, California.

During the course of routine identifications of fishes from the Western Atlantic and Gulf of Mexico at the University of Florida and at the U. S. Bureau of Commercial Fisheries Biological Laboratory at Brunswick, Georgia, it was thought that perhaps more than one species of *Poronotus* was being encountered. Preliminary investigations based on few specimens revealed the presence of a shallow-bodied Atlantic form and a deeper-bodied Gulf form. Fowler (1944:1) described the latter as a species of *Peprilus,* another stromateid genus, though it is clearly a form of *Poronotus* as determined by examination of the types which show a row of pores beneath the dorsal fin and much lower dorsal and anal fins. Fowler (p. 4) figured the pores and these fins properly and called (p. 2) particular attention to the pores. *Peprilus* lacks the pores and has high, falcate vertical fins. The two genera are easily distinguished. The types of *Peprilus burti* are especially deep-bodied, which may account for Fowler's generic placement. Specimens of *Peprilus* are usually deeper-bodied than most individuals of *Poronotus.* Fowler (1933: 61) had earlier identified these same specimens (as shown by labels in the jars with the types and by his own synonymy in describing *Peprilus burti*) as *Poronotus triacanthus. Peprilus burti* Fowler is therefore placed in the synonymy of *Poronotus triacanthus,* a wide-ranging species.

In view of the two seemingly geminate species or populations, large series of butterfish were assembled from throughout the range to analyze their variation. A number of meristic, proportional, and pigment characters were examined, but all except body depth were discarded because of extensive overlapping. Although quite variable and subject to overlap in local and regional stocks, body depth, on a mean basis using large numbers of specimens, does suggest the existence of three separate populations which may prove useful in future fishery studies on butterfish.

METHODS

Standard length (recorded to the nearest tenth mm.) was measured with dial calipers, placing one point of the jaws at the base of the mid-caudal rays (distal end of the hypural plate) and the other at the tip of the upper jaw with the specimen's mouth closed. Body depth was measured with one point of the dial calipers hooked over the exposed preanal pterygiophore and the other

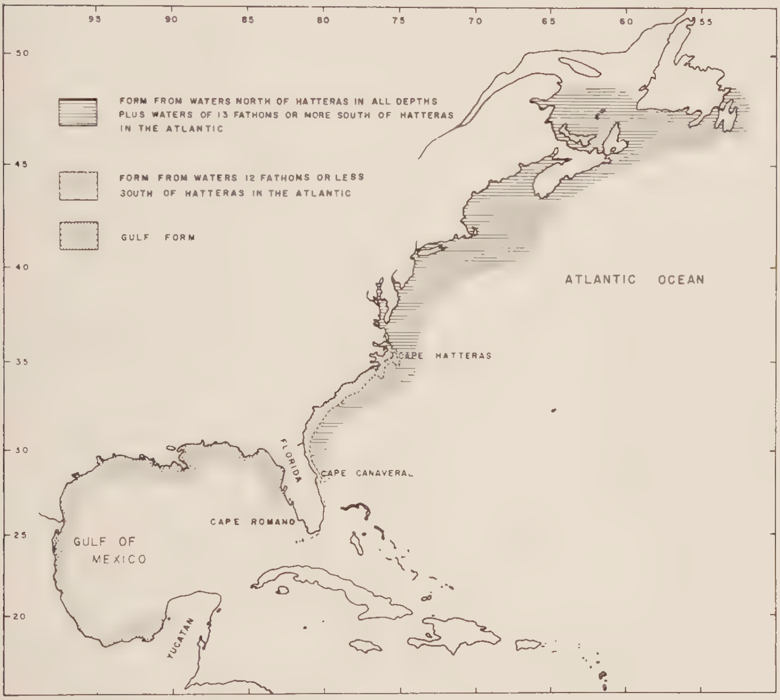

95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
FORM FROM WATERS NORTH OF HATTERAS IN ALL DEPTHS PLUS WATERS OF 13 FATHOMS OR MORE SOUTH OF HATTERAS IN THE ATLANTIC
FORM FROM WATERS 12 FATHOMS OR LESS SOUTH OF HATTERAS IN THE ATLANTIC
GULF FORM
ATLANTIC OCEAN
CAPE HATTERAS
FLORIDA
CAPE CANAVERAL
CAPE ROMANO
GULF OF MEXICO
YUCATAN

PLATE 7

Geographical distribution of *Poronotus triacanthus* (Peck). Three apparent populations, unnamed, are also shown. Dashed line off the south Atlantic coast denotes approximately the 10-fathom depth curve.

in a vertical from this point at the base of the dorsal fin. Standard length-body depth ratios were calculated to the nearest hundredth and rounded to the nearest tenth.

Water-depth data for a station often included a range through which the collecting gear (usually bottom trawls) was used (for example, "25 to 27 fathoms"). A mean depth value, rounded to the nearest fathom, was determined (in this example, 26 fathoms). Station localities are midpoints between the start and finish of trawling drags.

MATERIAL EXAMINED

Most of the specimens examined were obtained through the exploratory fishing operations in the Gulf of Mexico and in the Atlantic south of Cape Hatteras, North Carolina, by the U. S. Fish and Wildlife Service vessels OREGON, SILVER BAY, COMBAT, GEORGE M. BOWERS, and PELICAN. Additional material was obtained from shrimp trawlers in the Brunswick area and from crab bait brought from Portsmouth, Virginia, to the Lewis Crab Company at Brunswick. Gifts of material came from the University of Delaware through Dr. Donald P. deSylva and from the U. S. Bureau of Commercial Fisheries Biological Laboratory at Woods Hole, Massachusetts, through Robert L. Edwards. Specimens were borrowed from or examined at the following institutions: Academy of Natural Sciences of Philadelphia (types of *Peprilus burti*), through Dr. James E. Bohlke; University of Florida Collections, through Dr. John D. Kilby; Tulane University, through Dr. Royal D. Suttkus; University of Miami Marine Laboratory, through Dr. C. Richard Robins; U. S. National Museum, through Dr. Leonard P. Schultz; California Academy of Sciences, through Dr. W. I. Follett, and University of Georgia, through Dr. Donald C. Scott.

GEOGRAPHICAL RANGE

Based on literature, museum specimens, and station records from exploratory operations conducted by the U. S. Bureau of Commercial Fisheries, *Poronotus triacanthus* ranges (Plate 7) in the northwestern Atlantic from the outer coast of Nova Scotia and Cape Breton, and northward as a stray to the Gulf of St. Lawrence and to the south and east coasts of Newfoundland (Bigelow and Schroeder, 1953: 365), southward to 28°03′ N., 79°52′ W., in 150-175 fathoms (PELICAN station 25) and 28°03′ N., 80°29′ W., in 8 fathoms (SILVER BAY station 239) both in the vicinity (to the southward) of Cape Canaveral, Florida. There is an apparent discontinuity around the tip of the Florida peninsula to about Cape Romano (at 25°54′ N., 81°45′ W., SILVER BAY station 524) in the Gulf of Mexico. The species ranges widely around the perimeter of the Gulf to a recorded extreme of 21°45′ N., 91°30′ W., SILVER BAY station 341, off the western side of the Yucatan peninsula in Mexico.

Fishes ranging this far into Yucatan waters *may* also occur to the northeastern tip of the peninsula (Caldwell, 1955: 233). However, the butterfish may be somewhat restricted by bottom type. Bigelow and Schroeder (1953: 363) noted that in the northern part of its range the species shows an apparent preference for sandy bottoms, as opposed to rock or mud. A different situation

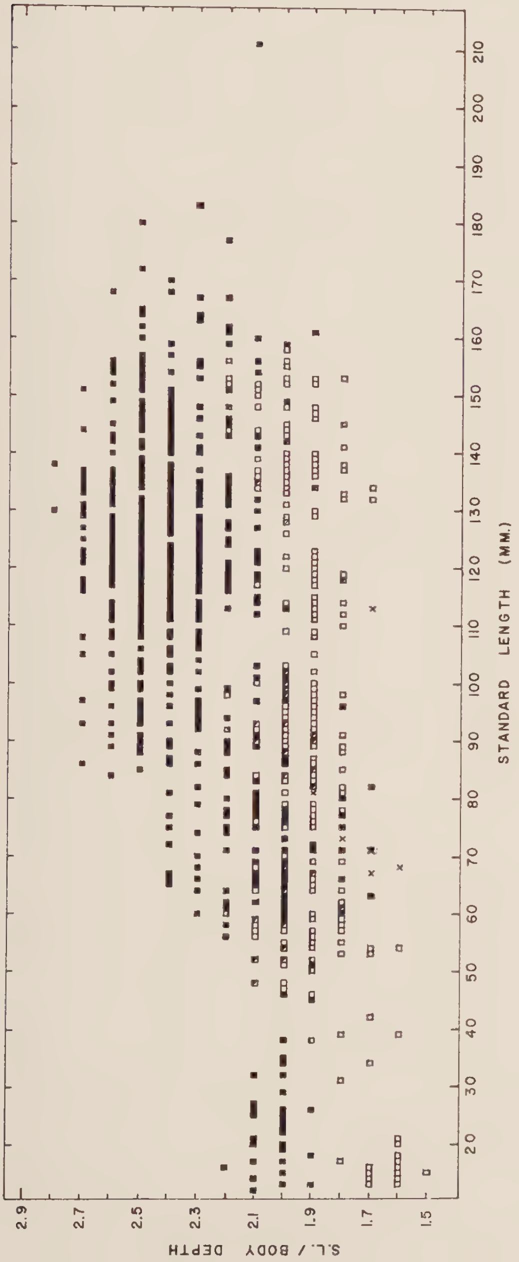


PLATE 8

Relationship between standard length and relative body depth for *Poronotus triacanthus* (Peck). Solid squares denote Atlantic specimens, open squares Gulf of Mexico specimens. Each symbol represents one or more individuals. Crosses denote types of *Peprilus burti* Fowler, a synonym.

seems to exist for the Gulf and for an inshore Atlantic form south of Hatteras. A soft bottom seems to be preferred, as determined from station data and hydrographic charts. This restriction may play a part in the distribution in the Gulf and on the Atlantic side of the lower part of the Florida peninsula. The bottom off the northern part of the Yucatan peninsula is generally hard (Lynch, 1954: 79).

Recent studies by Moore and Gorsline[3] show a hard bottom off the Atlantic Florida coast from somewhat south of Cape Canaveral southward. The offshore bottom on the Continental Shelf along the entire South Atlantic coast also is hard, extending inshore to about 10 fathoms, thus associating ecologically the deeper population noted below with the northern stock.

The Cape Romano specimen may be a straggler, or a misidentification (the record is based on an unsupported field report). Despite considerable exploratory work by the Service in the intervening area, there are apparently no other Florida records south of Big Sarasota Bay, Florida (about 27°30′ N.), California Academy of Sciences (CAS 17237). The nearest northerly record based on Service explorations (again, with much work in the intervening area) is at OREGON station 2158 (28°04′ N., 83°42′ W.) off Tarpon Springs, Florida. Thus, except for one possibly erroneous record, the waters of the entire southern half of the Florida peninsula are apparently devoid of butterfish. This break in range, possibly related to bottom type, may act as an effective barrier to gene flow between Gulf and Atlantic populations.

There are no records of *Poronotus* from the Caribbean, the Bahamas, or from Bermuda.

Population Analysis

The ratios of standard length to body depth for all specimens examined, regardless of size and depth of capture, were compared simply by plotting the ratios against standard length for the Gulf forms versus the Atlantic (Plate 8). Although many specimens from the two areas overlap, it is evident that many from the Atlantic are more slender than any of those from the Gulf. Examination of Plate 8 reveals that up to about 80 mm. standard length there is a tendency for relative body depth to decrease with increase in length. As this ontogenetic change tended to complicate the problem of geographic variation, only fish 80 mm. in standard length or larger were considered further. The geographic relationship discussed for adults holds for smaller specimens, however. The early development of *P. triacanthus* has been summarized by Pearson (1950: 87).

---

[3] Moore, Joseph E., and Donn S. Gorsline. *in press*. Physical and chemical data for bottom sediments South Atlantic coast of the United States M/V Theodore N. Gill cruises 1-9. Spec. Sci. Report — Fish., U. S. Fish and Wildlife Service.

There is also a slight tendency for specimens from deeper water to be shallower-bodied (Plate 9). However, since large series from both deep and shallow water produced individuals encompassing nearly the full range of relative body depths, as well as actual lengths, this factor was disregarded in considering populations.

Butterfish may occur in surface or midwater schools or at or near the bottom. Fathometer traces of butterfish schools were recently illustrated in a report of cruise number 65 of the OREGON. These indicate that a school (in March, at least) may extend through a considerable range of depth, from quite near the bottom up into midwater. Since it was not determined whether most specimens used in this study were taken on the bottom or by the trawl as it was going down or coming up (also noted by Bigelow and Schroeder, 1953: 364), water depths at the stations were used in making comparisons, although the fish themselves may have come from a somewhat shallower depth. There were so many catches in depths of 100 to 200 fathoms that the occurrence of the species at these depths is considered real.

Despite the above clouding phenomena, examination of series of adults provided evidence for the following populations when the factor of depth occurrence in the Atlantic specimens is also considered. (1) All of the Gulf forms. (2) The fish occurring south of Cape Hatteras to a depth of approximately 12 fathoms. (3) The fish south of Cape Hatteras occurring in depths of about 13 fathoms or more, plus those north of Cape Hatteras. These three populations are illustrated in Plate 7.

The exact depth division between the two populations occurring south of Cape Hatteras is difficult to determine because of inadequate samples in the 10- to 20-fathom range, but it apparently lies at about 12 fathoms, and there is undoubtedly some overlap between the two. Bottom type may, in fact, account for this distribution (see Geographical Range, above).

Bigelow and Schroeder (1953: 364 and 366) postulated a winter offshore movement in the north and at least south into Carolina waters. This is at variance with the results of this study, and except for the lack of records of specimens less than 45 mm. standard length from the deeper-water population south of Hatteras, possibly due to mechanical failures in collecting, two other factors seem to bear out the apparent validity of two groups in these more southerly waters: (1) ripe individuals have been taken

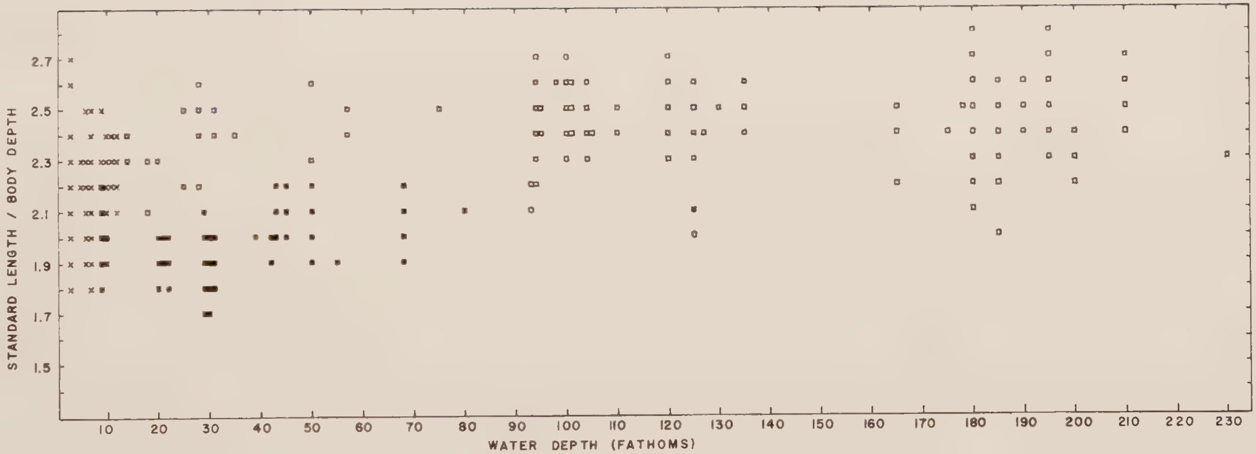


PLATE 9

Relationship between water depth and relative body depth of *Poronotus triacanthus* (Peck), greater than 80 mm. standard length, from the Gulf of Mexico (solid squares), waters 13 fathoms or greater south of Cape Hatteras plus all depths from north of Hatteras (open squares), and from waters 12 fathoms or less south of Hatteras (crosses). Each symbol represents one or more individuals. Note the specimens from the Gulf are not known out to as deep water as those of the Atlantic — despite extensive trawling in the Gulf to depths much greater than 125 fahoms.

from both populations, and there is thus apparently no significant spawning migration; (2) collections during each season of the year and in almost every month have produced specimens larger than 100 mm. standard length from most depths, including particularly the two populations.

The three populations were first visualized from preliminary studies on which Plate 8 is based, and proved clearer when the specimens from the Gulf and the Atlantic were compared in relation to water depth (Plate 9, considering the two Atlantic populations so depicted as one). They proved more valid when they were taken as groups and considered as such with reference to each other. The relationship between the populations of the Gulf and offshore south of Hatteras plus those north of Hatteras is graphically depicted in Plate 9. The actual numbers of specimens involved in each relationship are shown in Table 1. Based on Ginsburg's (1938: 261) arithmetical definition of the taxonomic concept, these two populations show a divergence of 70 percent and would therefore be considered subspecies. In such a case, the name *Poronotus tricanthus burti* (Fowler) would be available for the Gulf form (type locality, Breton Island, Louisiana) and *P. t. triacanthus* (Peck) for the Atlantic form, since Peck's type came from the Piscataqua river in New Hampshire (Peck, 1800: 48). A synonym of *P. triacanthus, Stromateus cryptosus* Mitchell (1815: 365), also came from northern waters — New York Bay.

However, when the Atlantic inshore population south of Hatteras is compared with the two above, Plate 9 and Table 1, it completely overlaps both, with the exception of two very slender individuals, and on a mean basis, relative body depth for this population also lies intermediate between those of the others. Series of specimens from about 3 fathoms in the Brunswick shrimp trawling area span this range, and the great variation is considered real rather than being an artifact showing the influence of ecological overlap in the 12-fathom range mentioned earlier in this paper. While on a mean basis this inshore Atlantic population can be distinguished from the other two, the overlap which thus links all three seems to make it useless to try to distinguish the three on a nomenclatorial basis.

Therefore, while the knowledge of the existence of three apparent major populations of butterfish should prove useful in management of the species, for the present it seems that no useful gain would be had in naming them. *Peprilus burti* Fowler, actually *Poronotus burti* (Fowler), is placed in the synonomy of *Poronotus triacanthus* (Peck) until such time that some future studies prove taxonomic distinction valuable. The three populations do seem to be in a process of divergence through geographical and ecological isolation (in the Atlantic, especially bottom, depth, and/or possibly temperature related to geography and depth), but at present they seem merely to represent a cline, with the extremes arithmetically distinguishable on a mean basis as subspecies. The extreme variation in relative body depth within this species is illustrated in Plate 10.

ACKNOWLEDGMENTS

Aside from the persons noted above as having furnished material, I am especially indebted to Harvey R. Bullis of the U. S. Fish and Wildlife Service at Pascagoula, Mississippi, for specimens from the exploratory vessels under his charge and for the opportunity to examine the station records from those vessels. Frederick H. Berry, now of the Bureau of Commercial Fisheries Biological Laboratory at La Jolla, California, examined the holotype and two of the paratypes of *P. burti* and also made many useful suggestions at the onset of the study. Much assistance and many helpful comments came from members of the staff of the Brunswick Laboratory. Of these, I am particularly indebted to William W. Anderson, Jack W. Gehringer, and my wife Melba C. Caldwell for their critical examination of the manuscript.

LITERATURE CITED

Bigelow, Henry B., and William C. Schroeder
1953. Fishes of the Gulf of Maine. First revision. Fishery Bulletin, U. S. Fish and Wildlife Service, vol. 53, no. 74, pp. 1-577, figs. 1-288.

Caldwell, David K.
1955. Distribution of the longspined porgy, *Stenotomus caprinus*. Bull. Marine Sci. Gulf and Caribbean, vol. 5, no. 3, pp. 230-239, figs. 1-3.

PLATE 10

Specimens of *Poronotus triacanthus* (Peck) showing variation in relative body depth (given below in parentheses). Top to bottom: 130.4 mm. S.L., (2.8), from SILVER BAY station 470, 29°48′ N., 80°12′ W., 195 fath. off St. Augustine, Florida; 129.7 mm. S.L., (2.4), from about four fathoms near Portsmouth, Virginia; 131.8 mm. S.L., (2.1), from about four fathoms near Portsmouth, Virginia; 131.9 mm. S.L., (1.7), from SILVER BAY station 844, 20°01′ N., 91°47′ W., 30 fathoms off Campeche, Yucatan. Disregard the differences in color and color patterns.

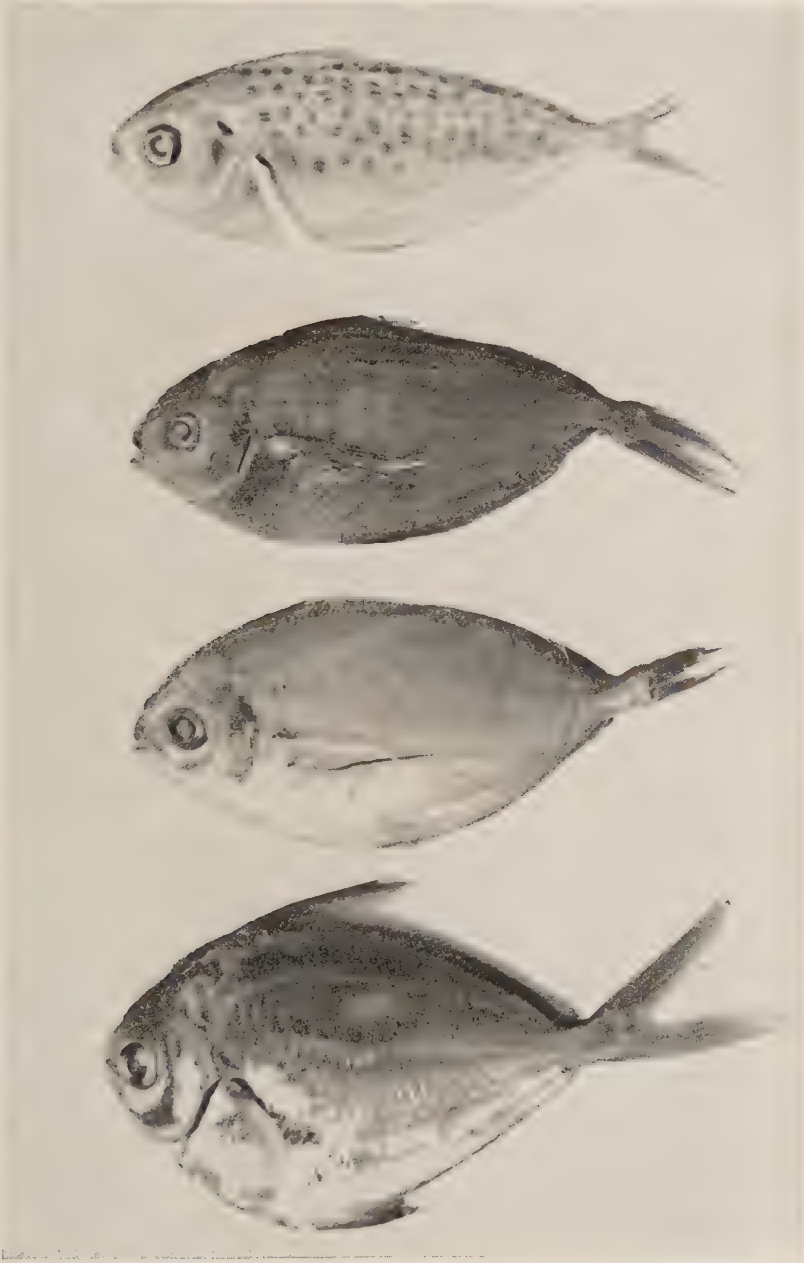


PLATE 10

Fowler, Henry W.
1933. Notes on Louisiana fishes. Proc. Biol. Soc. Washington, vol. 46, pp. 57-64. (ref. copied).
1944. Description of a new genus and a new species of American stromateid fishes. Notulae Naturae, vol. 142, pp.1-4, figs. 1-2.

Ginsburg, Issac
1938. Arithmetical definition of the species, subspecies and race concept, with a proposal for a modified nomenclature. Zoologica, vol. 23, no. 13, pp. 253-286, figs. 1-4.

Hildebrand, Samuel F., and William C. Schroeder
1928. Fishes of Chesapeake Bay. Bull. U. S. Bur. Fish., vol. 43, no. 1, pp. 1-366, figs. 1-211. (for 1927).

Lynch, S. A.
1954. Geology of the Gulf of Mexico. *In* Galtsoff, Paul S. (Coordinator). Gulf of Mexico. Its origin, waters, and marine life. Fish. Bull., U. S. Fish and Wildlife Service, vol. 55, no. 89, pp. 67-86, fig. 16.

Mitchell, Samuel L.
1815. The fishes of New York, described and arranged. Trans. Lit. Philos. Soc. New York, vol. 1, pp. 355-492, pls. I-VI.

Pearson, John C.
1950. The young of some marine fishes taken in lower Chesapeake Bay, Virginia, with special reference to the gray sea trout *Cynoscion regalis* (Bloch). Fish. Bull, U. S. Fish and Wildlife Service, vol. 50, no. 36, pp. 79-102, figs. 1-26.

Peck, William D.
1800. Description of four remarkable fishes, taken near the Piscataqua in New Hampshire. Mem. Amer. Acad. Sci., vol. 2, no. 2, pp. 46-57. (ref. copied).

Table 1. — Frequency distribution of relative body depths in *Poronotus triacanthus* (Peck) 80 mm. standard length or more.

Population	Mean	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
1. Gulf of Mexico in all depths.	2.0 (1.95)	3	25	75	78	19	7						
2. Atlantic south of Cape Hatteras from depths of 12 fathoms or less.	2.2 (2.19)	1	2	9	17	28	28	38	12	3	2	1	
3. 3a and 3b combined.	2.4 (2.44)				5	12	29	72	120	147	85	26	2
3a. Atlantic south of Cape Hatteras from depths of 13 fathoms or more.	2.5 (2.46)				3	8	12	46	77	96	62	20	2
3b. North of Cape Hatteras in all depths.	2.4 (2.42)				2	4	17	26	43	51	23	6	

GRAY SQUIRRELS LARCENOUSLY FEEDING AT CRACKER-VENDING MACHINES[1]

David K. Caldwell[2] and Melba C. Caldwell[2]
United States Fish and Wildlife Service

In a recent paper, Layne and Woolfenden (1958: 595) described an unusual food source, that of insects from car radiators, exploited by the gray squirrel, *Sciurus c. carolinensis.* This note describes a circumstance of gray squirrels feeding from an unusual source directly provided by man, *ie.*, cracker-vending machines.

Briefly and anonymously mentioned in the local newspaper (Brunswick News for March 7, 1960, p. 12) several weeks previous to our observations, we first witnessed the activity of the squirrels during the last week of March, 1960, at the Wanderer Motel, a large hostelry located adjacent to the open ocean beach, on Jekyll Island, Georgia. Our observations were corroborated by employees of the motel who told us that they frequently observed the squirrels in the act of feeding in this same manner.

While the island is heavily wooded and supports abundant wildlife, the immediate site of the motel has been subjected to considerable clearing, with the result that only a few oak trees remain to support the local population of squirrels. This has probably been an important contributing factor in driving the squirrels to this unusual foraging activity.

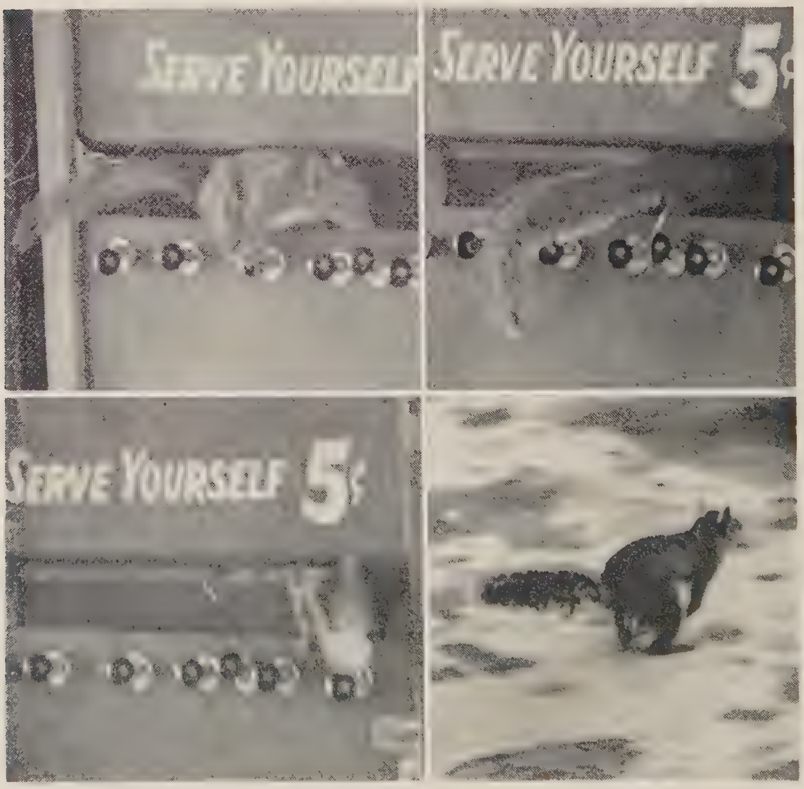
Three commercial vending machines of the type which dispense small packages of cellophane- or waxed paper-wrapped crackers, cookies, and candy are visited by the thieves. The machines are located at different places along the very long motel building, each placed in a small hallway open at each end so that the squirrels have easy access and escape routes. A fourth machine, while in a place open to the outside, is so situated that the squirrels would have to go into a very confined area to rob it. They do not visit this machine.

---

[1] Contribution No. 55, U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

[2] Present address: Los Angeles County Museum, Los Angeles, California.

The same procedure was followed by each squirrel in obtaining the crackers. Jumping and climbing up into the slot where the crackers normally are dispensed (Fig. 1), the squirrels thrust their forelegs, head, or even the entire body (except the tail) up out of sight into the mechanism of the machine (Fig. 2). The intact package of crackers could not be dislodged, so the squirrels tore and bit open the cellophane wrapping and extracted one of the four crackers (Fig. 3). Returning to the ground, the larcenous squirrels carried the cracker away to consume it (Fig. 4)—often a matter of a hundred yards or more. We did not observe their doing so, and, according to the employees questioned, the squirrels apparently never eat the cracker in the immediate vicinity of the



Figures 1-4. Left to right, top to bottom. 1. Squirrel jumping into slot. 2. Body thrust up into mechanism of machine. 3. Emerging with cracker. 4. Going away with cracker to consume it in a safe place.

machine—probably because of its relatively enclosed and insecure location and its proximity to considerable human activity. Other crackers in the package were extracted in a like manner until the last one or two remained. The squirrels could then remove these, still enclosed in cellophane, and carry them away. The wrapper was never left at the machine, but was always carried away, leaving only crumbs on the ledge of the slot to mark the theft. Only crackers were taken—possibly due to the ease with which the package could be opened (the candy was in heavy wax paper) and the contents extracted. Malt-flavored peanut butter and cracker sandwiches were most often selected, though cheese-flavored ones were also taken. This also was most probably due to the greater ease with which the slot containing this type of cracker could be robbed, a fact which we determined by reaching up into the slots and feeling the packages in place.

At least three squirrels were involved, and probably more. These three converged on the motel from different directions, and always from those directions. At one time, two of them were in the act of robbing different machines just after the third had departed and was still in sight.

We could not guess whether the cracker machines were discovered by the squirrels through independent activity or by learning from others. We *did* observe that at least one of the squirrels was aware of the presence of at least two of the machines, for being disturbed just before entering one, it made its way directly to a second machine where it obtained a cracker. The machines are several hundred feet apart and out of line of sight.

Activity seemed to take place intermittently, mostly during the daylight hours of early morning and late afternoon—particularly so in the early morning while activity at the motel was still limited.

A similar phenomenon was recently pictured and briefly discussed (Anonymous, 1960: 128) for an unnamed species of squirrel (*Sciurus griseus* ?) at the San Diego Zoo in California. In this instance, whole peanuts were taken from a commercial vending machine. The bags apparently were torn in a like manner as the squirrel could not take the entire package from the machine.

We wish to thank William W. Anderson and Jack W. Gehringer, of the U. S. Fish and Wildlife Service at Brunswick, for the critical examination of the manuscript.

Literature Cited

ANONYMOUS

1960. Culprit caught with the cache. *Life Magazine*, 48(9): 128, for March 7.

LAYNE, JAMES N., and GLEN E. WOOLFENDEN

1958. Gray squirrels feeding on insects in car radiators. *Jour. Mammalogy*, 39(4): 595-596.

Quart. Journ. Fla. Acad. Sci., (1960) 23(4), 1961.

Reprinted from
THE JOURNAL OF THE ELISHA MITCHELL SCIENTIFIC SOCIETY
Volume 77, Number 2—November, 1961

16

INTERRELATION OF FUNCTIONAL MORPHOLOGY, BEHAVIOR, AND AUTECOLOGY IN EARLY STAGES OF THE BIVALVE *MERCENARIA MERCENARIA*

M. R. CARRIKER

Department of Zoology, University of North Carolina, Chapel Hill, N. C.
Institute of Fisheries Research, University of North Carolina, Morehead City, N. C.

INTERRELATION OF FUNCTIONAL MORPHOLOGY, BEHAVIOR, AND AUTECOLOGY IN EARLY STAGES OF THE BIVALVE *MERCENARIA MERCENARIA*

INTERRELATION OF FUNCTIONAL MORPHOLOGY, BEHAVIOR, AND AUTECOLOGY IN EARLY STAGES OF THE BIVALVE *MERCENARIA MERCENARIA*

M. R. Carriker[a]

Department of Zoology, University of North Carolina, Chapel Hill, N. C.
Institute of Fisheries Research, University of North Carolina, Morehead City, N. C.

Introduction

The hard clam or quahog, *Mercenaria mercenaria* (Linne 1758) (formerly *Venus mercenaria* Linne), Family Veneridae (Frissel, 1936; Turner, 1953; H. Wells, 1957; Aldrich, personal communication) principally inhabits the shallow, more saline coastal waters along the eastern and gulf coasts of North America from Nova Scotia to Yucatan and is harvested in large quantities as a wild crop. Although adult stages of the species have received considerable study (see review, Carriker, 1959), the larval stages have been given much less attention, and efforts to propagate the bivalve on a commercial scale are only now beginning to be successful. Early stages in the life history of the venerid are most vulnerable to depredations of enemies, yet their study in the laboratory and in the field has been possible only within the last decade or so during which laboratory culture of the larvae has been accomplished (Loosanoff, 1954).

In memory of

Thurlow Christian Nelson

This paper reports results of studies on, and interrelation of, functional morphology, behavior, and autecology of swimming and early bottom-dwelling stages of *Mercenaria mercenaria* in the laboratory and in the field. These studies were made by the author and associates during the period from 1947 to 1956 in New Jersey, New York, and North Carolina. Before 1950 the only report of consequence on the biology of the early stages of *M. mercenaria* in the literature was by Belding (1912), who reported briefly on the general embryology of the larvae through the straight-hinged stage and on the general anatomy and habits of the byssal stage. He was able to raise the larvae only to the straight-hinged stage and obtained newly set byssal stages in open boxes in the field. In the last decade Loosanoff and associates have made substantial contributions to knowledge of the culture and physioecology of the larvae in the laboratory (Loosanoff, 1953, 1954, 1958, 1959b; Loosanoff et al., 1950, 1951a, 1951b, 1953a, 1953b; Davis, 1958; Davis et al., 1956, 1958; Chanley, 1958; Lindsay and Woelke, 1960); and Carriker (in both laboratory and field, 1950b, 1952, 1956) and Turner and George (in the laboratory, 1955) have reported results of preliminary studies on the behavior of pelagic and early post-set stages.

To make accurate identification of veligers of *M. mercenaria* in native waters possible and to supply a large quantity of veliger and post-set stages for laboratory investigations, we reared young individuals under field laboratory conditions. We were aided substantially by larval-culture technics which Loosanoff and associates were developing at the time and generously shared with us.

For the most part we conducted our investigations during the summer months. In New Jersey (1947–1951) laboratory facilities and living accommodations were provided by the Oyster Investigation Floating Laboratory, the "Cynthia," a houseboat which we moored each summer in a tidal creek adjacent to the body of water in which field studies were made (Carriker, 1961). Tide level, salinity, water and air temperatures, barometric pressure, rainfall, wind, and cloudiness of the sky were recorded routinely from the "Cynthia" to provide information used in connection with study of spawning, culture, behavior, and larval distribution and movements of the hard clam. A twenty-six-foot flat-bottomed cabin boat (a New Jersey "garvey") with inboard engine and equipment for pumping plankton samples, dredging, and washing sediment samples facilitated field work.

In the summer of 1947 we moored the "Cynthia" in Landing Creek and conducted field studies in Great Bay (Fig. 1). This estuary is six statute miles long and four miles wide

---

[a] Now at the U. S. Bureau of Commercial Fisheries Biological Laboratory, Oxford, Md.

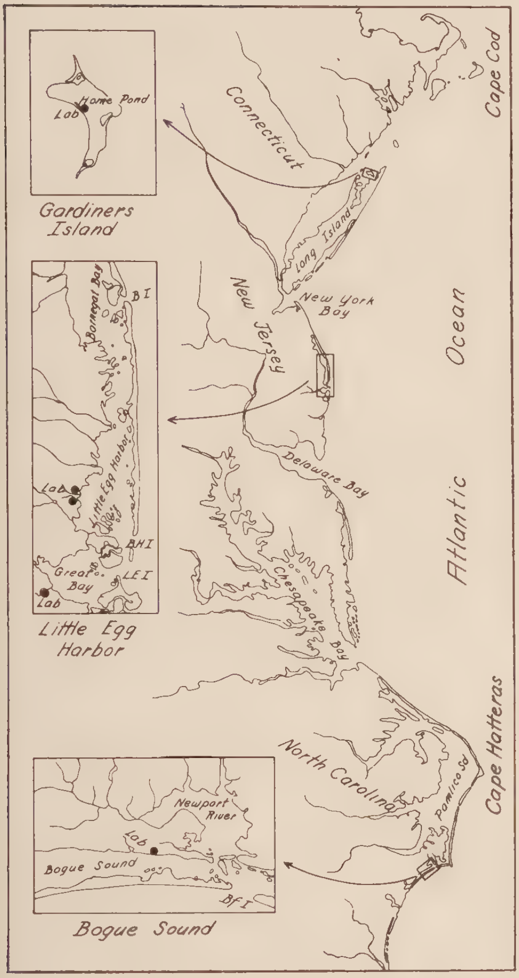


FIG. 1. Chart of east coast of the United States from Cape Cod to Cape Fear, showing location of study areas and magnified insets of these areas: Little Egg Harbor, New Jersey, 1947–1951; Gardiners Island, New York, 1953–1955; Bogue Sound, North Carolina, 1956. BI, Barnegat Inlet; BfI, Beaufort Inlet; BHI, Beach Haven Inlet; LEI, Little Egg Inlet.

and has an average depth at mean low water of six feet. It opens to the Atlantic Ocean through numerous deep channels by way of Little Egg Inlet and receives large volumes of fresh water from the Mullica River. Maximum current velocities in the middle of the estuary in 1947 approximated 0.8 ft./sec. Spring range of the tide was four feet, summer salinities in the middle of the bay ranged from 18 to 31 $^0/oo$, and water temperatures from 21° to 30°C. Sediments varied from clean fine sand near the inlet to highly organic mud in the quieter upper reaches of the estuary. Sparse populations of *M. mercenaria* were scattered over the lower reaches, providing clams for limited commercial tonging. Carriker (1951b) describes the hydrography and fauna of this bay more fully.

We moored the "Cynthia" in Ezras Creek in the summer of 1948 and in Thompson Creek in the summers of 1949–1951. Both are small tidal creeks draining across a salt marsh one to three miles in width eastward into Little Egg Harbor, where we conducted field studies (Fig. 1) (Carriker, 1961). A small cabin beside Thompson Creek became an annex for culture of larvae of *M. mercenaria.* No running sea water was available in our laboratory. In contrast with Great Bay, Little Egg Harbor receives only a small flow of fresh water from small streams, and, in spite of continued harvesting by local clammers, at the time of our studies was inhabited by dense populations of *M. mercenaria.* The detailed hydrography of Little Egg Harbor is treated in a subsequent section on the ecological study of larvae of *M. mercenaria* in the field.

No field studies were conducted in 1952. During the summers of 1953–1955 we made our investigations on Gardiners Island, New York (Fig. 1). A small cabin equipped with running sea water on the eastern shore of Home Pond provided our laboratory facilities. The sea water system consisted of a hard rubber pump, lead and hard rubber pipes, and a wooden reservoir. A heating unit (sea water passed through lead coils in tap water heated by gas flame) in the system heated sea water for artificial spawning of *Mercenaria,* and we had a small rowboat with an outboard motor for making field studies in Home Pond and the other three large ponds on the island. Home Pond is a shallow open-inlet 21-acre arm of Gardiners Bay with a maximum amplitude of 2.4 feet. Fresh water entering the pond comes in as rainfall and seepage from surrounding forested slopes. During the three summers salinities ranged from 22 to 33 $^0/oo$ in the pond, while those in Gardiners Bay seldom fell below 28 $^0/oo$. The bottom of the outer half of the pond consisted of clean sand; the inner half, fine organic mud. There were dense populations of *M. mercenaria* in the pond, especially in the inlet and vicinity; these were not harvested commercially. See Carriker (1959) for a description of the hydrography of Home Pond and vicinity.

In the summer of 1956 research shifted to the University of North Carolina Institute of Fisheries Research in Morehead City (Fig. 1) on Bogue Sound. Here a study of the culture and behavior of young *Mercenaria* in the laboratory received prime emphasis. Constantly running sea water was pumped (hard rubber pump) to and distributed in the laboratory in non-toxic plastic (polyethylene) pipe (Carriker, 1957). Bogue Sound is a long, narrow, shallow coastal-plain lagoon separated by a narrow barrier island from the Atlantic Ocean to which it communicates by an inlet at each end. Most, if not all, of the sea water off the laboratory entered the sound through Beaufort Inlet. The sound receives relatively little fresh water; salinities, which fluctuated slightly from week to week, rose from 31 to 36 $^0/_{00}$ during the course of the summer. Temperature of the sea water entering the laboratory varied between 23° and 31°C., but remained above 27°C. most of the season. *M. mercenaria* occurred in moderate abundance in Bogue Sound (Chestnut, 1952) and supported a small commercial fishery.

I LABORATORY CULTURE OF YOUNG *MERCENARIA*

When we began our studies in 1947 there was very little information available in the literature on the biology of the early stages of *M. mercenaria,* and identification of the larva was in doubt. The papers of Stafford (1912), Belding (1912), Nelson (1921), and Wells (1927) provided illustrations and in some cases descriptions, but these were not in agreement. Stafford and Nelson attempted identification by tracing development of successively older stages in the plankton. Belding achieved fertilization of ova and grew larvae to the straight-hinged stage in the laboratory. Wells, the first to carry larvae to the late stage in the laboratory, published good photomicrographs of them but omitted descriptions; unfortunately identification of larvae from illustrations alone is difficult and unreliable. Comparable stages of the larvae illustrated by Wells and by Belding resemble each other, but not those of Stafford and Nelson.

During the summer of 1947 we made negligible progress in identifying the larvae of *M. mercenaria,* since our laboratory-reared larvae developed only to the trochophore stage. In 1948 we reared them to a length of 142 μ. Concurrently Nelson, Haskin, and Gibbs, at the Cape May laboratory on Delaware Bay in New Jersey, grew them to a setting size of 208 μ; and during the winter of 1948–1949 Loosanoff (personal communication; Loosanoff and Davis, 1950) for the first time cultured them to the setting stage in large numbers. Culture of larvae of *M. mercenaria* in the laboratory from gametes of known parents thus made possible positive identification of these larvae in plankton of native waters (Carriker, 1950b). Our larvae resembled those described by Belding (1912) and by Wells (1927) and those reared by Loosanoff. At the same time Sullivan (1948) published a description and illustrations of a larva which she misidentified as *Mercenaria mercenaria* by tracing development of larval stages in the plankton. This larva resembles the one described by Nelson (1921) as *M. mercenaria* and is remarkably similar to an unidentified bivalve larva which we found in moderate abundance in Great Bay, Little Egg Harbor, and Bogue Sound, and which during the summer of 1947 we too mistook for the larva of *M. mercenaria.*

Profiting from the larval culture technics of Loosanoff and associates (personal communications; Loosanoff and Davis, 1950, 1951a; Loosanoff, 1953, 1954; Loosanoff et al., 1953a, 1953b), we reared larvae through post-setting stages during the summers of 1951 in Little Egg Harbor, 1953–1955 on Gardiners Island, and 1956 in Morehead City. (This last represents the first time that larvae of *M. mercenaria* have been cultured successfully in the laboratory in the southeastern United States [Carriker, 1957].) We developed routine methods for collection, preparation, and artificial stimulation of adults for spawning; for artificial fertilization of ova; and for cleaning and feeding and observing planktonic and post-set stages of *M. mercenaria.* In the application of these procedures we made several observations on the requirements and culture of the larvae, some of which are reported here. Part of these confirm similar observations reported by Loosanoff and associates and by Turner and George (1955), and others are recorded for the first time.

Spawning

Of 2,890 individuals of *M. mercenaria* placed in spawning trays during the course of six summers, 12 per cent spawned, a result close to the 17 per cent figure obtained by Loosanoff (1937) in similar laboratory spawnings.

Clams were dug by hand, raked, or tonged, and a sample opened for macro- and microscopic examination of gonads and gametes. Potential spawners were then brushed and washed thoroughly and arranged in trays of still or running clean sea water of a salinity approximating that of sea water at high tide where the clams were collected. If temperature of the water was below 23°C., it was raised to about 28°C. by immersion of the spawning trays in larger trays of warm water or by heating the running sea water directly. Temperatures much above 28°C. caused many clams to pump more slowly, or even to close. After the clams had been thermally conditioned for an hour or so and most were pumping actively, we added a few cubic centimeters of a dense suspension of active sperm to the water in the vicinity of the incurrent siphon of each clam. (In a number of bivalves, including the hard clam, spawning is a group reaction stimulated by a hormone carried on the sperm [Nelson and Haskin, 1949].) If necessary, subsequent additions were made from time to time. Sperm were obtained by stripping males with well-developed gonads: integument was sliced from the gonads of several individuals, and with a bulb pipette enough sperm were teased and flushed from the gonads into a beaker of filtered sea water to provide a milky white suspension. We took care to avoid cutting the digestive diverticulum in order to prevent introduction of digestive enzymes. Tissue fragments were removed from the suspension by decantation. Only active motile sperm were utilized; the degree of activity was checked under a magnification of 440X, at which the slightly curved sperm heads, 6 to 8 μ in length, with their long flagella, could be seen whirling in small circles. Stripped sperm in a dense suspension were active as long as six hours at between 22° and 24°C. Loosanoff (1954) has shown that viability of gametes of *Mercenaria* is unrelated to size or age of parents, and we therefore selected parents at random from those available.

A common response of *Mercenaria* to the addition of sperm, particularly when ready to spawn, was to open the siphons more widely and pump more vigorously. Ready-to-spawn (physiologically mature) clams started spawning five minutes to one hour after addition of sperm, males invariably spawning before females (also see Loosanoff, 1937). Refractive individuals did not spawn for several hours.

Clams siphoned and responded more actively to sperm stimulation in water which had been warmed from a temperature below 25°C. or cooled from a temperature above 28°C. (also see Loosanoff and Davis, 1950; Turner and George, 1955) than in water of a constant high temperature; and there was also a more active response in running sea water than in still sea water. Because of the high temperature of the water entering the laboratory at Morehead City from Bogue Sound (27° to 31°C. much of the summer) warming the water to induce spawning was unnecessary. The spawnings that occurred were obtained in the late afternoon and evening as water and air temperatures dropped, and several hours after the addition of the sperm. Infrequently in all areas clams spawned as a result of thermal change alone.

Spawning of the first male in any tray soon started other males spawning, and later the females also. These individuals were then moved gently to separate containers of filtered sea water to complete spawning.

Emission of gametes continued in spite of such molestations as jarring of the container, partial change of water by dipping or siphoning, and movement of the spawner to another container. Duration of continuous emission was variable depending, among other factors, upon the fullness of the gonad and recent spawning history. Maximum observed continuous emission for females was 10 minutes, and for males 35 minutes.

Gametes are voided through the excurrent siphon. In males, sperm are emitted in a white thread-like stream which frays out of macroscopic vision some 1.5 to 2 inches from the siphon tip; in females ova are generally released in a steady loose granular white spray which fans broadly just outside the siphon tip, and since ova measure approximately 125 μ in diameter (including a clear gelatinous envelope; also see photograph, Loosanoff and Davis, 1950) they remain visible macroscopically. Occasionally females voided ova in the form of pellets which accumulated beneath the siphon.

Conditioning and spawning temperature of the water ranged between 25° and 28°C. The maximum temperature of induced spawning was 29°C. and minimum temperature, 23°C. This minimum, which was associated with a spawning on Gardiners Island, was the prevailing temperature for some hours before the addition of sperm to the spawning tray. H. J. Turner and J. Hanks (personal communication) in early June in Massachusetts spilled a small quantity of sperm and ova into a water table where spawning stocks of *Mercenaria* were being maintained in water at 19°C. A wave of mass spawning started at the upper end of the water table and progressed through the population for fifteen feet. This is the lowest temperature recorded for spawning in the laboratory; note that Loosanoff (1951b) has shown that newly fertilized ova fail to develop normally at temperatures of 15°C. and below.

Table I

Frequency of spawning of *Mercenaria mercenaria* in the laboratory in New Jersey, New York, and North Carolina during the summer months, 1948–1956.

Periods spawning attempted	New Jersey				New York						North Carolina			
	1948		1951		1953		1954		1955		1956		1956 Va.–refr.	
	No. clams used	Clams spawned, %	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
June 1–10.....	—	—	—	—	—	—	—	—	—	—	144	1	72	14
11–20.....	—	—	—	—	—	—	13	23	31	58	48	38	13	85
21–30.....	—	—	82	5	—	—	23	86	—	—	80	0	10	10
July 1–10.....	49	0	89	1	86	20	82	78	147	5	—	—	9	78
11–20.....	72	24	278	15	68	6	23	4	—	—	40	0	23	9
21–31.....	78	26	89	1	40	8	60	53	221	0	—	—	—	—
Aug. 1–10.....	—	—	284	1	22	27	—	—	—	—	40	0	9	33
11–20.....	48	0	102	0	49	16	18	78	265	1	—	—	—	—
21–31.....	—	—	74	4	10	90	—	—	—	—	—	—	—	—

Frequency of spawning in the laboratory varied somewhat in the three geographic areas (Table I). Most abundant and consistent spawnings were obtained in 1954, and minimal success was achieved with North Carolina clams in 1956. In New Jersey the peak of spawning came in July; in New York good spawnings were obtained over much of the summer during the first two years, but only in June of the last summer. In North Carolina *Mercenaria* had spawned partially to completely before June 1–8, when a survey of the condition of gonads in clams from different areas was made. Gonads of clams from warmer waters of Core Sound, Black Sound, and Bogue Sound were more nearly depleted than those of clams from bottoms near inlets. Between June 1 and August 9, 352 clams from these sounds were placed repeatedly in spawning trays; one spawned on June 5 and twenty-one on June 12, and thereafter no further gametes were obtained.

Retardation of Spawning. Because frequently the bulk of spawning occurred early in the season, it became increasingly difficult to induce spawning as the summer season advanced. Retardation of spawning by retention of clams at low temperatures (Loosanoff and Davis, 1951a) helped to circumvent this difficulty and made possible the rearing of larvae in Morehead City, where zygotes from local *Mercenaria* never developed. We had observed, as did Loosanoff (1937), that clams in shallow water begin to breed earlier than those in the deeper, colder parts of the sounds, especially near inlets. Thus on June 15, 1953, we harvested unspawned *Mercenaria* from deep water off Greenport, Long Island, and kept them in a cold room at approximately 15°C. in shallow enamel trays of sea water which was changed weekly. As late as eight weeks after harvesting, they spawned profusely when stimulated by sperm and increased temperatures. Their larvae developed normally to the setting stage. After nine weeks in the cold room, most individuals spawned fully, but larvae were abnormal and did not metamorphose.

In Morehead City we obtained a supply of unspawned *Mercenaria* from Cheasapeake Bay, Virginia, on June 1. These we housed in a refrigerator at between 5° and 10°C. in trays of still sea water, except for a daily period of an hour when they were immersed in warm running sea water in the laboratory to feed. Larvae from clams maintained under these conditions over the period of a month developed normally to the setting stage, but veligers from animals kept thus longer than a month displayed anomalies.

Loosanoff and Davis (1951a) delayed spawning of clams and made available viable gametes through the summer and fall by transferring individuals with physiologically mature gonads in May from Long Island Sound to Boothbay Harbor, Maine, where water temperatures in the summer were between 5° and 8°C. lower than in Long Island Sound.

Fertilization

Fertilization of ova was accomplished in large shallow trays by addition of a few cubic centimeters of sperm suspension for each liter of dense ova suspension. Frequently the number of sperm used to induce spawning was sufficient to fertilize all ova obtained. Use of excess sperm resulted in abnormal development of embryos. In all three geographic areas fully spawning, vigorous females that eliminated ova quickly and abundantly produced the most vigorous, fastest-growing, most viable larvae. Embryos developing from ova released in pellets, or from ova released some time after stimulation and in small quantities, often did not metamorphose. Satisfactory development of embryos resulted from fertilization of naturally released ova by either active stripped or naturally released sperm. Fertilized stripped ova never developed (also Loosanoff, 1937).

Culture Methods

As soon as the first polar body was evident, embryos were washed gently with clean cotton-filtered sea water through a three-inch stainless steel screen No. 100 (pore size 165–210 μ) onto a second screen No. 325 (pore size 45–65 μ) to remove excess sperm, mucus, fecal strings which had accumulated in the spawning tray, and tissue fragments and blood from the stripped gonads and were stored in shallow trays of filtered sea water. In less than 12 hours embryos developed to active ciliated gastrulas, and in 16 to 24 hours into early straight-hinged veligers. Twenty-four-hour-old veligers were then transferred to glass or earthenware crocks, ranging in volume from 1 to twenty liters, in concentrations averaging from 5 to 10 larvae per cubic centimeter of sea water. Densities of 50 larvae per cubic centimeter were raised to metamorphosis in 11 days in 1951, but in general larvae in concentrations much above 10 per cubic centimeter grew less rapidly and were subject to higher mortality. Loosanoff et al. reported (1953a) similar observations. Richards (1933) reported that stainless steel screens are nontoxic when used in the culture of *Mytilus edulis* ranging in length from 5–8 mm. over a period of 41 days in still sea water changed every third day; their use in the culture of clam larvae by Loosanoff and associates and by us confirms Richards' observations.

In early culturing efforts we placed hard-clam larvae in glass tunnels covered at each end with silk bolting cloth and suspended in the water over the side of the "Cynthia" in Thompson Creek. However, insufficient exchange of sea water and lack of food prevented development much beyond the straight-hinged stage. This failure led during the summer of 1951 to the use of the Browne plunger jar (Fig. 2 [Browne, 1897; Lebour, 1933; Bruce et al., 1940; Lebour, personal communication]), in which we reared several broods past the setting stage. In the meantime Loosanoff et al. (1951b) found that aeration of cultures in unnecessary. Consequently, after 1951 we employed only still-water cultures without supplementary aeration of any kind.

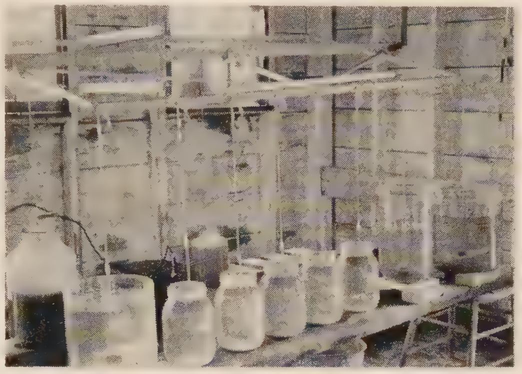


FIG. 2. Plunger jars and oscillating frame employed in culture of *M. mercenaria* during summer of 1951 in Mott's cabin, Thompson Creek, Little Egg Harbor, New Jersey.

Approximately every two days the sea water in the larval culture jars was replaced completely with cotton-filtered sea water collected at high tide. When sea water from a laboratory running-sea-water system was used, presence or absence of deleterious metals and other toxic substances in the system was checked by rearing larvae concurrently in controls consisting of sea water hauled manually in enamel or glass containers. During water changes larvae were siphoned onto a three-inch stainless steel screen through rubber tubing held securely to the sides of the screen by means of a large one-hole rubber stopper. The culture jar was washed and the residue rinsed onto a second screen to retain larvae remaining in the residue. As larvae grew in size we used successively coarser screens No. 250 (maximum pore size [that is, diagonal dimension of square opening], 110 μ) and No. 150 (pore size, 150 μ) to retain them. Fresh food microorganisms were added after each change of sea water, and daily if the larvae cleared the water of planktonic algae during the previous day.

After larvae metamorphosed and began creeping on the bottom of the culture jar, we removed only about four-fifths of the water at each change, since individuals at this stage adhere tenaciously to substrata and are readily transported on screens to contaminate other cultures when the same screen is employed in cleaning several jars. To eliminate the possibility of such transference we dipped screens in fresh water after each change. This causes clams to withdraw the foot between the valves and permits flushing them from screens. The practice of partial removal of water left detritus on the bottom of culture jars which (see page 189) provided a medium for burrowing by older stages.

Larvae survived air temperature fluctuations ranging between 13°C. and 30°C. in our laboratories.

*p*H of the sea water in larval cultures usually fluctuated between 7.8 and 8.0.

SUPPLEMENTAL FEEDINGS. Food micro-organisms were first added to each new larval culture soon after the straight-hinged stage was reached. We did not have an opportunity to determine whether growth of preshelled stages could be accelerated by addition of glucose and/or amino acids which might become available to them through absorption from sea water, but this should be investigated. In Little Egg Harbor and on Gardiners Island approximately 35 cubic centimeters of a dense suspension of algal cells were added to each liter of sea water containing 50 larvae per cubic centimeter; correspondingly lesser quantities were contributed to sparser larval cultures. In 1955 and 1956 algal cells were added in quantities recommended by Loosanoff et al. (1953b) and a haemocytometer was used to determine algal concentrations.

Attempts during the summers of 1947 and 1948 to raise larvae without supplemental feeding—that is, relying on a daily or twice daily change of sea water to provide necessary nutrients—were unsuccessful; at best larvae could be carried to a maximum length of only 170 μ before they died in 12 to 18 days.

During the last summer in Little Egg Harbor and the three summers on Gardiners Island, supplemental food of mixed micro-organisms dominated by *Chlorella* sp. (young cells averaged 3 μ in diameter), cultivated by a method modified from that recommended by Loosanoff and Davis (1950), was provided routinely to many of our larval cultures.[1] On the whole, however, in contrast with the success of Loonsanoff and Davis (1950), we were able to raise hard clam larvae to setting on mixed culture of *Chlorella* in only occasional larval cultures; and in these setting did not start until the fourteenth day after fertilization, and growth was accompanied by excessive mortality.

In Little Egg Harbor in 1951 optimum results in growing hard-clam larvae were obtained by feeding them a mixed culture inoculated with *Chlorella* cells and fertilized heavily (10 g. per liter) with 6–3–6 organic fertilizer alkalized with marble chips. These food cultures passed through a succession of several colors and odors over a period of from three to four weeks before they were fed to the larvae. Both whole culture and filtrate (from Whatman filter paper No. 42, which probably permitted a sizeable fraction of smallest micro-organisms to pass) raised larvae to post-setting stages in large numbers. Fastest-growing larvae reached setting size in ten days, with very little mortality. On Gardiners Island, however, *Chlorella* cultures fertilized with 2, 3, and 10 grams of fertilizer per liter, as well as filtrates of these, gave results inferior to or similar to those obtained with the standard mixed culture of *Chlorella* fertilized with 1 gram per liter.

Maximum survival and setting of larvae on Gardiners Island was achieved by adding pablum extract to the culture water. Fifteen cc. by volume of commercial cereal pablum flakes were soaked in 100 cc. of sea water for two hours and filtered through Whatman paper No. 41; one-tenth of a cc. of this filtrate was added over a period of four days to each liter of larval culture every second day following the change of sea water; subsequently 0.5 cc. of filtrate was added every second day. This quantity of filtrate, accelerating growth of bacteria and other micro-organisms, raised larvae in duplicate cultures to the setting stage in fourteen days. Larval cultures became slightly milky in appearance a few hours after addition of the filtrate. Even with this method considerable mortality of larvae still occurred.

---

[1] Food organisms were cultivated in sixteen-liter (five-gallon) wide-mouth glass jars in cotton-filtered sea water collected at high tide, and were fertilized with 6–3–6 or 5–3–5 organic fertilizer in a concentration of 1 g. per liter. Jars were agitated at least three times daily, and cells clinging to inner surfaces of jars were scraped free to permit maximum penetration of daylight, up to 400 foot-candles near screened laboratory windows. When cells in the first jar produced a dense green color (2,000,000 to 7,000,000 cells per cc.), a four-liter inoculum from culture was sufficient to produce a dense population in a new sixteen-liter culture in two or three days. Dense cultures were harvested at the rate of two liters of suspension per day; sea water was replenished as suspension was withdrawn, and fertilizer was added at the rate of 0.5 g. per liter of suspension removed. Best cultures were harvested almost continuously for as long as a month and provided a continuous crop of young cells. Occasionally some of the cultures turned yellow from insufficient light (during overcast days, light in the laboratory fell below 100 foot-candles on Thompson Creek and Gardiners Island, where no electricity was available), from dense growth of ciliates and naked flagellates which fed on the cells of *Chlorella*, or from our own overharvesting.

Feeding mixtures of pablum filtrate and mixed culture of *Chlorella* to larvae demonstrated that they tolerated higher concentrations of the pablum filtrate (up to 2 cc. per liter) in the presence of the *Chlorella*, but otherwise produced variable results, associated probably with the nutritive value of the mixed culture of *Chlorella*. For example, in one series of larval cultures we could not rear larvae on mixed culture of *Chlorella* alone beyond a size of 156 μ, yet in combination with pablum filtrate, metamorphosis was obtained in ten days with relatively little mortality. Conversely, in a second series, pablum filtrate, when added with mixed culture of *Chlorella*, produced no difference in growth or survival rate from that rendered when it was added alone. In a few larval cultures, mixed culture of *Chlorella* retarded growth rate of the larvae. During the four summers in Little Egg Harbor and on Gardiners Island, a total of 111 larval cultures were started, and metamorphosis occurred in 19 per cent of these.

We obtained our best results in rearing larvae of *M. mercenaria* in Morehead City, where in the course of the summer we established thirty cultures. Seventy-seven per cent of these rendered abundant larvae which reached the post-setting stage. We prepared a variety of larval foods to insure at least one which would permit cultivation of large populations of metamorphosed clams. Among them were unialgal cultures (not bacteria free) of *Chlorella*, *Nannochloris*, and *Chlamydomonas* which we established in cotton-filtered sea water, in heat-treated cotton-filtered sea water (about 70°C. for 30 minutes), in heated cotton-filtered sea water treated with bone charcoal, and in autoclaved sea water. Algal cultures were placed in three-gallon glass jars under aeration in a porch which faced north and received from 400 to 800 foot-candles of daylight on sunny days, being shaded with screens on the east and west. One *Chlorella* culture was fertilized with 5–3–5 organic fertilizer (Loosanoff and Engle, 1942), the others with Rice's (1953) modification of Miquel's solutions. In spite of high summer temperatures these species of algae multiplied rapidly, and all cultures except those in autoclaved sea water soon contained dense mixed populations of *Nitzschia*, naviculoids, and other contaminating micro-organisms which entered in sea water. Sea water in Bogue Sound, particularly that in the eastern end, which was moderately polluted and provided the source of our laboratory running sea water, contained so high a content of nutrients that addition of one gram per liter of 5–3–5 organic fertilizer caused the usual bloom of micro-organisms attributed in our New Jersey studies to overfertilization.

Of the species of algae used, cells of *Nannochloris* fertilized with Miquel's solutions grew most rapidly, reaching concentrations of 20,000,000 cells per cubic centimeter in short periods.

We also used Fleischmann's "active dry" yeast in sea water, cooked soluble starch (1 mg. per liter), and pablum filtrate as food.

Hard-clam larvae grew most rapidly when fed mixed culture of either *Nannochloris* or *Chlorella*. On a diet of one or the other alone, they started to set in eight days. Least mortality occurred on a diet of *Nannochloris*. Post-set clams also grew well on these two mixed foods. However, unialgal cultures of *Nannochloris* cultivated in autoclaved sea water under sterile conditions produced an inferior food on which the larvae grew poorly or not at all. Good growth was also achieved by larvae fed on pablum filtrate, starch, yeast, and *Chlamydomonas* cells; these started setting in from eight to thirteen days, but considerable mortality took place. The addition of pablum filtrate to mixed culture of *Nannochloris* increased total shell length of the fastest-growing larvae in laboratory sea water by about 100 μ in twenty days, though this growth rate did not approach that by larvae reared in water hauled from the sound and fed mixed culture of *Nannochloris* alone.[2] (Faster-growing larvae raised under the latter conditions reached lengths ranging from 0.88 to 1.10 mm. in twenty-seven days.)

---

[2] The effect of different kinds of sea water in our culture of larvae was tested as follows. Duplicate cultures of hard-clam larvae fed on a mixed culture dominated by *Nannochloris* were grown in (a) sea water hauled in enamel buckets from Bogue Sound, (b) sea water taken from the laboratory running-sea-water system, (c) laboratory sea water heated to 70°C. for 30 minutes, and (d) sea water heated to 70°C. for 30 minutes

Although mixed algal cultures are not always reliable, since occasionally a culture becomes dominated by an undesirable micro-organism, they afford an easily cultured nutritious larval food. Recently Davis and Guillard (1958) demonstrated that *Chlorella* constitutes a less nutritious food for larvae than *Monochrysis lutheri* and *Isochrysis galbana*. Thus it would appear, as also suggested by the low nutrient value of unialgal populations of *Nannochloris* in our cultures, that other micro-organisms than *Nannochloris* and *Chlorella* were being utilized by our clam larvae. Turner (1955) found *Nitzschia closterium* a suitable food for *M. mercenaria* larvae raised in his laboratory. This species was easily cultivated in quantity and lacked toxic properties even in high densities.

A singular lack of uniformity of results in culturing larvae of *M. mercenaria* to metamorphosis under apparently similar conditions within a single season and in different seasons and in different regions[3] led us to the hypothesis that an unidentified substance(s) of sporadic distribution in native waters may be correlated with success in culturing these larvae. Loosanoff and associates (Loosanoff, 1954, 1958) have reached the same conclusion. Our success in rearing clam larvae in North Carolina may be related to this phenomenon, and this in turn to the presence of moderate pollution in the sea water employed. We concur with Loosanoff that complete control of laboratory experimentation involving marine animals requires that these substances be characterized and further suggest that efforts be made to develop artificial sea water of known and reproducible composition for use in experimental study of marine animals.

STUDY OF INDIVIDUAL CLAMS. We studied the behavior, growth, and form in individual veligers and early post-set stages of *Mercenaria* in running-sea-water microculture dishes constructed as follows. A collar of plankton cloth (18XXX) 3 cm. high was fastened to a watch crystal (1 cm. high and 2.6 cm. in diameter) with clean melted paraffin (Fig. 3). Several dishes were placed around a 2.5-liter evaporating dish and each connected with this by means of siphons bent from glass tubing 3.5 mm. in diameter. The opening of each siphon in the reservoir ranged from 200 to 250 μ in diameter and in the microculture dish, 500 to 700 μ. When the bottom of a microculture dish was placed 1.5 cm. below that of the reservoir, each siphon delivered about one drop per second when the reservoir was full and about one drop in six seconds when the container was nearly empty. This rate of flow

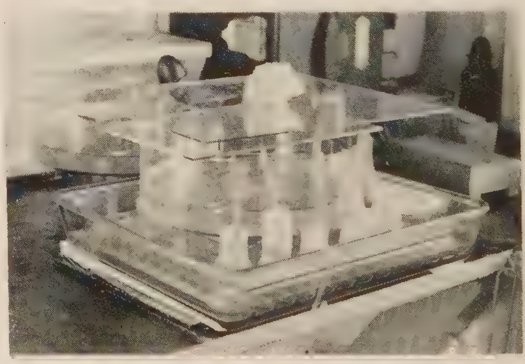


FIG. 3. Running sea water microculture dishes for culture of individual larval and early post-set *M. mercenaria*.

---

and treated with bone charcoal. Larvae grew most rapidly and with negligible mortality in (a); they started to set in eight days, and all larvae metamorphosed by the twentieth day, at which time the larger ones measured 0.55 mm. in length. In (b) setting commenced in eleven days, also with negligible mortality; and also in twenty days all larvae had set; the largest measured 0.33 mm. in length. In (c) and (d) larvae grew very slowly; an occasional larva started to set in thirteen days, and by twenty days only a few had fully set in (c) and very few in (d). Maximum lengths at the end of twenty days averaged 240 μ in (c) and 220 μ in (d); some mortality occurred in both cultures. The experiment suggests that laboratory running sea water (the intake pipe was heavily fouled with living sessile organisms at the time), heat-treated sea water, and charcoal-treated sea water each successively removed more of some "substance" from the water which is necessary for growth.

[3] At least part of our difficulty in raising clam larvae on Gardiners Island may have been the presence in many of our cultures of the parasitic fungus *Sirolpidium* (Davis et al., 1954), which we identified within numerous larvae during the summer of 1954. We encountered no such parasite in Morehead City, but a small copepod, *Tisbe* (= *Idya*) sp., a common co-inhabitant of many of our clam larval cultures which fed on the algae and reproduced actively, inhibited feeding to a slight degree by moving rapidly over newly set clams. The copepods entered cultures in sea water as young stages and then could not be removed mechanically because their size range corresponded with that of clam larvae. Loosanoff et al. (1957) have since developed a chemical control for these crustaceans.

produced a relatively constant gentle circulation in each microculture dish. Introducing additional reservoirs siphoning in series provided a system which operated unattended for twenty-four hours. Approximately 35 cc. of mixed algal food culture, screened through a No. 325 stainless steel screen, per liter of fresh sea water were added daily to the reservoirs. The flow of sea water through the plankton-cloth collar of each dish was maintained for about two weeks by occasional brushing of the cloth and removal of detritus accumulating within the dish with a small bulb pipette. When the plankton cloth fouled, *Mercenaria* were transferred to clean collared dishes by means of finely drawn glass bulb pipettes. After metamorphosis, larvae tended to remain on the bottom, and clogging of the plankton cloth and flow of water over the top of the collars was less likely to carry clams out. The addition of a thin layer of fine sand to the dish further reduced wandering of clams.

Thirty-five *M. mercenaria* ranging in length from 135 to 295 μ (these included both individuals cultured in the laboratory and some captured with the plankton net in native waters) and were isolated in microculture dishes. Maximum growth was obtained by a larva which was collected in Little Egg Harbor when it was 177 μ in length. It was maintained in captivity for 31 days and during this time grew to a length of 480 μ.

II FUNCTIONAL MORPHOLOGY

Definition of Early Stages of Life Cycle

During larval development and metamorphosis the young of *M. mercenaria* pass through a series of well-defined recognizable stages characterized by distinct structural features and behavior. Table II suggests a terminology for these stages which is based, when these are available and suitable, on terms already employed in the literature of bivalve larvae (Werner, 1939; Jørgensen, 1946; Rees, 1950; Quayle, 1952). Stages are defined principally on the basis of valves, locomotor organs, byssus, siphons, and the spatial position of the animal in its native habitat. Valve dimenions accompanying the appearance, and in some cases subsequent disappearance, of larval organs are only generally diagnostic of larval and post-setting stages, since shell dimensions of successive stages overlap broadly in different individuals. Thus length limits given in Table II are offered only as rough indicators of the stages, and those given for early post-set stages are incomplete. The position and behavior of young hard clams in the native habitat change with each successive major morphological development; thus identification of stages is useful in studies not only of functional morphology and physiology, but also of behavior and autecology.

Planktonic Stages

1. Nonshelled

When first discharged by the female, ova of *M. mercenaria* are slightly grayish and granular in appearance. They vary in diameter from about 60 to 85 μ and are surrounded by a conspicuous, clear, gelatinous envelope about 25 μ in thickness (see Figure 1, Loosanoff and Davis, 1950). The envelope soon swells and in four hours may attain a thickness of 95 μ, giving a large ovum an over-all diameter of approximately 270 μ. By the late gastrula stage, the embryo, still in the gelatinous envelope, whirls rapidly on its long axis. In 12 hours at room temperature the early trochophore, which is oval in shape, emerges from the envelope; it has a dense mat of long cilia over the equatorial region and a prominent single apical flagellum. How the embryo escapes from its gelatinous envelope has not been described. The embryo is now approximately 85 μ long and its apical flagellum equals the length of the embryo. It swims rapidly through the water, holding the flagellum straight in front of it; when held under a cover glass the embryo periodically whips the flagellum basally. In about 16 hours the trochophore assumes a spherical shape, and a broad area of long velar cilia, 7 μ in length, develops around the base of the apical flagellum; short cilia clothe the remainer of the embryo. Shortly thereafter, when it has length of about 90 μ, the embryo starts secretion of prodissoconch I valves, and at an age of 20 to 24 hours the fully shelled straight-hinged veliger appears (Figs. 4, 5). Appearance of the valves does not seem to decelerate swimming rate, possibly because the size and efficiency of the velum keep pace with the growing larva. (See Belding [1912] for a description of the general embryology of the early stages of the hard-clam larvae, which he could raise only to the straight-hinged stage.)

Table II

Summary definition of early stages of the hard clam, *Mercenaria mercenaria,* based on laboratory-reared animals.

A. Planktonic Stages:

1. Nonshelled: development from fertilized ovum through blastula, gastrula, and trochophore to nonshelled veliger stage occurs in about 16 hours. Early stages float passively in water currents; trochophores and naked veligers actively propel themselves through the water by means of a strongly ciliated velum (Fig. 1, Loosanoff and Davis, 1950).
2. Shelled (*prodissoconch*):

a. *Straight-hinged veliger:* possesses smooth valves; velum continues to grow in size and larva is a strong swimmer; length range, 90-140 μ, age range, 1-3 days (Figs. 4, 5).	a. *Prodissoconch I* (not synonymous with straight-hinged veliger): first valves: thin, uniform, transparent, secreted by surface of mantle, appear during first 24 hours of life (Figs. 4, 5, 6).
b. *Umboned veliger:* smooth valves continue to grow symmetrically, but now a gently sloping umbone projects above middle of hinge line; length range, 140-220 μ, age range, 3-20 days (Figs. 5, 6).	b. *Prodissoconch II* (Werner's *veliconcha stage*, not synonymous with umboned veliger): valves added to Prod. I by edge of mantle and mantle surface after first 24 hours of life during remainder of veliger stage, still smooth but with growth striae (Figs. 5, 6).

B. Pediveliger (swimming-creeping) stage:

At an age varying from 6 to 20 days and a length ranging from about 170 to 220 μ in different individuals, the veliger gains use of a foot, and thereafter alternates swimming in water and crawling on the bottom; the stage appears to endure for a variable period in different individuals and terminates at a shell length ranging from about 200 to 230 μ, when the velum is lost (Fig. 6).

C. Plantigrade ("crawler," dissoconch) benthic stages:

After the velum is lost and beginning at a length ranging from 200 to 230 μ in different individuals, locomotion in the metamorphosing larva is limited to crawling on the foot on the bottom:

1. Byssal Plantigrade: soon after—and sometimes before—losing the velum, the plantigrade affixes to the substratum by means of a byssus (thus reaching the *setting,* or "spatting," stage); thereafter for a number of weeks (to a shell length of approximately 9 mm.) it alternates byssal attachment and active crawling, remaining on or superficially in the sediment; siphons form, and as they lengthen the clam moves deeper into the sediment; shell secretion now takes the form of concentrically ridged dissoconch valves, small primary ridges being followed by more conspicuous secondary ridges (Fig. 7).
2. Juvenile Plantigrade: young clams approximately 9 mm. and longer in which the byssus gland is no longer functional, the byssus is lost, and the animal maintains its position beneath the surface of the sediment by means of the foot alone; definitive siphons are fully developed (Fig. 12).

2. Shelled

Straight-hinged Veliger. The early straight-hinged veliger has a stippled gray appearance with a slight tinge of translucent grayish-salmon color which fades to clear at the edges of the valves. Stippling is uneven and most pronounced in the center. Globules occur throughout the protoplasm, range in color from clear to dark gray, occur in a loosely scattered pattern, and vary in size from 1 to 14 μ (Figs. 4, 5).

An early straight-hinged veliger of average dimensions, when first fully covered by valves, possesses a length (maximum anterior-posterior distance parallel to the hinge line) of 98 μ, a height (maximum distance between the hinge line and the ventral curvature of the valves) of 78 μ, a hinge line 65 μ long, and a width (maximum distance between external surface of the two valves) of 48 μ. Although the ratios of these dimensions remain relatively constant, the size of larvae varies considerably, lengths as small as 86 μ being recorded by Loosanoff et al. (1951b).

When held between a cover glass and a slide, straight-hinged larvae commonly swim against the surface film of air bubbles in a stationary position, actively beating the cilia of the velum. Under these circumstances it has been possible to obtain the dimensions of the velum and its parts. A larva 125 μ in length possessed a velum 65 μ in diameter, velar cilia about 20 μ in length, and an apical flagellum

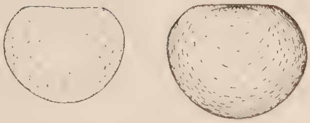


FIG. 4. Detailed drawings of straight-hinged veligers of *M. mercenaria* reared in the laboratory. Left, 100 µ long, 250X; right, 120 µ long, 260X.

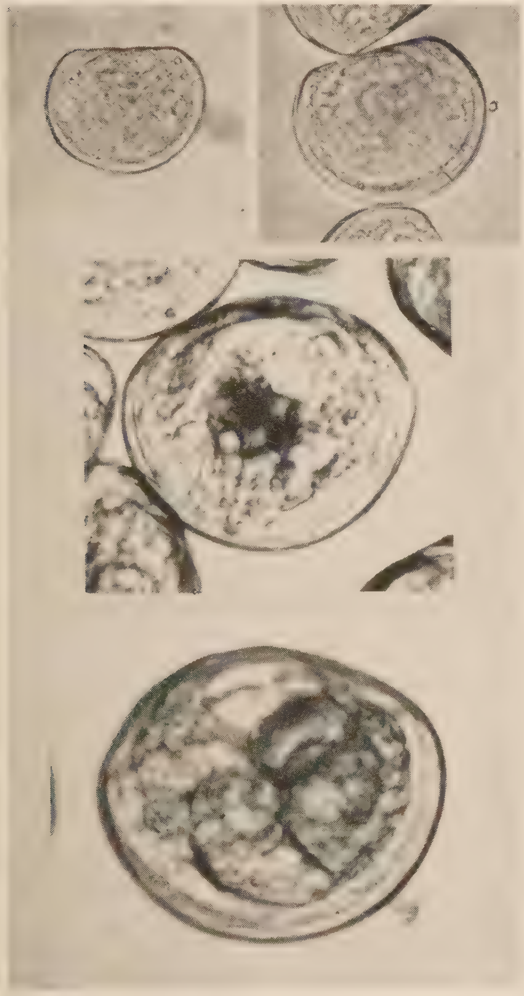


FIG. 5. Photomicrographs of veliger larvae of *M. mercenaria* reared in the laboratory. Top left, straight-hinged veliger 90 µ long, 230X; top right, straight-hinged veliger 115 µ long, 230X; middle, early umboned veliger 145 µ long, 270X; bottom, late umboned veliger 180 µ long, 260X (photomicrographs by T. C. Nelson).

35 µ in length. Viewed from the hinge line (a dorsal view) with valves fully opened and velum active, rapidly beating velar cilia resemble a vibrating halo as their tips project beyond the sides of the valves. Velum retractor muscles, leading from the region of the hinge line to the inner circular base of the velum, are visible in swimming larvae at a magnification of 100X.

Valves of straight-hinged veligers are asymmetric, one end being slightly pointed and the other rounded; the hinge line is relatively long in proportion to the length and height and is straight (Fig. 4). Occasionally empty veliger shells were collected in plankton samples and compared closely with those of larvae cultured in the laboratory. Valves of natives did not differ significantly in appearance from those reared in the laboratory.

Initial shell material, prodissoconch I, which covers the earliest straight-hinged veliger, is very thin, transparent, smooth, and fragile. This is the stage which Werner (1939) called the "veliger"; the D-shaped shells covering it he called "prodissoconch I." Werner's use of the term veliger, however, is too restricted, since the larva possesses the velum throughout its planktonic existence. The term prodissoconch I for the first valves has gained acceptance and is used here; but Werner's term veliger will be extended in this paper to include all stages possessing the velum (Table II).

UMBONED VELIGER. Shell deposited after prodissoconch I, and for the remainder of the planktonic veliger existence, is characterized by mintue growth striae, though the over-all aspect of the shell surface is smooth. This secondary larval shell Werner calls prodissoconch II, and the larval stage accompanying it he names, appropriately, the "veliconcha" stage.

Infrequently prodissoconch II valves were collected in the plankton in which the edge of a valve had been broken off accidentally and replaced by new shell, in much the same manner as adult clams renew fringes of valves lost through unsuccessful attempts of predators to penetrate them. At a length of about 120 µ a pronounced line in the form of a smooth arc appears just under the hinge line at a point where the umbones are forming. Under a magnification of about 430X, minute punctate markings may be seen over the nascent umbones (Fig. 4, right). These markings are not visible in the photomicrographs (Fig. 5). A narrow band of light yellow color appears in the shell material itself as a rim around the outer margins of the valves (prod. II). This color is present in empty valves, and therefore is not pigment in underlying tissues. The medial part of the shell (prod. I) is colorless. Tips of the umbones in the late straight-hinged veliger, at a shell length of 130 μ, approach close to the hinge line. At a length of approximately 140 μ the larva, now known as an early umboned veliger, is characterized by umbones which rise slightly but uniformly above the hinge line (Fig. 5, middle), and the punctate markings on the external surface of the umbones become more conspicuous. The band of light yellow shell around the valve margins persists.

Between a total shell length of 140 to 200 μ, umbones in the veliger continue to rise gradually but inconspicuously above the hinge line, giving the larva a rounded appearance in lateral profile (Fig. 5, bottom). Umbones never assume the prominence represented by those of the late veliger stages of *Crassostrea, Teredo*, and *Anomia*. As the umboned veliger of *M. mercenaria* grows, its straight hinge is eclipsed, one end of the larva becomes slightly angled while the other remains rounded, and shoulders off the ends of the umbones slope gently. Light yellow shell margins persist even on a diet of various micro-organisms possessing different pigments.

Whereas most tissues of healthy living clam veligers are grayish in color, the digestive diverticulum is often brightly pigmented, the color varying somewhat with the quality and quantity of the diet. As also reported by Loosanoff et al. (1951b), we observed that actively feeding veligers cultured in the laboratory at one time or other exhibited digestive diverticula ranging in color from light yellow to orange-brown to bright orange to green, the color of the diverticula corresponding more or less with that of food organisms. Diverticula of native larvae collected in the plankton likewise varied in color. Starved larvae in the laboratory possessed noticeably less pigment. Loosanoff et al. (1951b) state that color of larvae of *M. mercenaria* is not a reliable diagnostic taxonomic character. It should be emphasized, however, that it is the color of the digestive diverticulum which is so variable; pigmentation of the valves themselves is more reliable.

Under a magnification of 150X freshly consumed food particles, averaging 1 to 2 μ in diameter, were seen actively rotating in little clusters in the stomach, propelled by active gastric cilia. Larger particles than this were not observed in veligers, suggesting that ordinarily larger food organisms may not be ingested.

Pediveliger Stage

Toward the end of its pelagic existence the veliger develops a strong, mobile, highly ciliated muscular foot and for an indefinite period alternates between a planktonic and benthic habit (Fig. 6). According to Thorson (1957) the conjecture that larvae of many bottom invertebrates are able to respond positively or negatively to the substratum receives support from the "swimming-crawling stage," which seems to be a normal feature in development of lamellibranchs and marine gastropods, allowing them to crawl and carefully examine the substratum in which they have settled and then to swim up again. Because no term for this stage exists in the literature, and because of its ecological significance, the writer introduced the term "pediveliger" for it (Carriker, 1956 [misspelled "pedoveliger" in this publication]). Thorson (1946, 1950) suggests that probably most pelagic larvae have the capacity to postpone metamorphosis while seeking suitable substrata for the young, bottom-dwelling stage. In the hard clam, pediveliger "searching" (if indeed such occurs) is facilitated by the presence of both the velum and the foot. Whether metamorphosis in *M. mercenaria* is delayed in the absence of suitable substrata has not been determined. This should be investigated (Lynch, 1959).

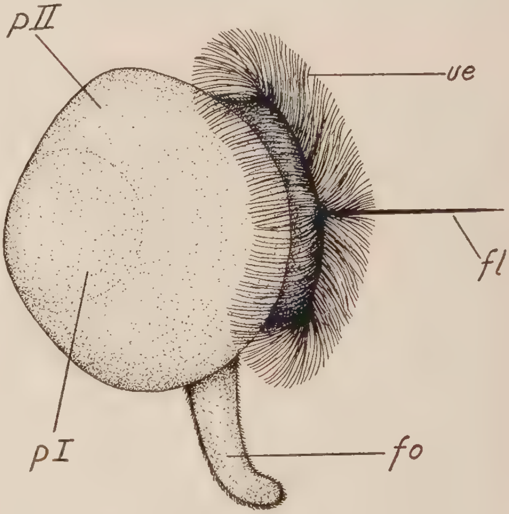


FIG. 6. Detailed drawing of pediveliger of *M. mercenaria* 200 μ in length, 210X. fl, apical flagellum; fo, ciliated foot; pI, prodissoconch I; pII, prodissoconch II; ve, ciliated velum.

At a length ranging from about 200 to 230 μ, and after the foot has developed, the pediveliger loses the velum and takes up life on the bottom. The velum is not resorbed, but individual cells are shed and swim in the water for some time (Turner, personal communication). Raven (1958) speaks of the shedding of the velum in bivalve mollusks as a catastrophic event in which metamorphosis proceeds at first gradually and accelerates with a precipitate casting off of the whole velum in fragments. Cole (1938) reports from a careful study of the larval organs in the metamorphosis of *Ostrea edulis* that the bulk of the velar tissue is broken up and cast off or eaten, and the apical area of the larval velum forms the basis of the upper labial palps of the spat.

Loosanoff et al. (1951b) define metamorphosis in the hard clam as a "gradual replacement of a ciliated velum with a large muscular foot and ending with the development in the foot of a functional byssal gland." We infer that reference here is not to morphological displacement of the velum by the foot, since both organs are simultaneously functionally present in the pediveliger, or to the histological details of velar loss, but is rather a general statement of the process. Belding (1912) writes that the foot seems gradually to obliterate the velum, which can be seen in different stages of degeneration; the ciliated tip of the foot assumes the swimming function of the velum and the foot propels the clam through the water by a kicking movement. We are not able to confirm the functioning of the foot in this manner.

Internal anatomical changes accompanying metamorphosis have not been studied, and deserve attention. In this connection the study by Quayle (1952) of anatomical changes occurring during metamorphosis of the venerid bivalve *Venerupis pullastra* should be cited.

We concur with the observations of Loosanoff et al. (1951b) that hard-clam larvae obtained from a single pair of parents and grown under identical laboratory conditions often display considerable individual variation in the rate of growth and duration of the pelagic phase. These researchers found in their cultures that the maximum range of length of plantigrades at which setting occurred was from 175 to 236 μ, though it took place most commonly within a size range of from 200 to 210 μ. Larger larvae did not always set before smaller ones. Rate of growth of individuals within a single population varied widely: in some instances the length of larvae in a culture during the onset of setting ranged from 100 to 200 μ. Studying the effect of temperature on the rate of development of larvae, Loosanoff and associates found that at a constant temperature of 18°C. setting began 16 days and terminated 24 days after fertilization, and that at 30°C. setting began 7 days and ended 16 days after fertilization of ova. In general, within the temperature range of from 18° to 30°C. rate of growth increased with a rise in temperature. Loosanoff (1959) also discovered that the shape and size of metamorphosing larvae is not altered by development in different temperatures, a fact of some significance when the size and shape of prodissoconch II are employed in identification of the larvae. Landers (1954), in a three-year field study of the seasonal abundance of clam larvae in Narragansett Bay, Rhode Island, found that length of larvae of *M. mercenaria* in his samples ranged from 200 to 225 μ, when they disappeared from the plankton at the time of setting.

Plantigrade Stage

DISSOCONCH VALVES. With the genesis of dissoconch valve secretion by the outer surface of the outer fold of the mantle margin, distinct lamellate ridges appear on the external surface of the valves of byssal plantigrades (Fig. 12a–f). These consist of thin, more or less periodic elevations of shell surface which are concentric with the shell margin and run entirely around the valves from the hinge line. They were first observed by Belding (1912). Earliest ridges (here designated primary shell ridges), which are coincident with early life of the newly set byssal plantigrade on the surface of the sediment, are small and set close together and consist of soft, chalky-white shell material (Fig. 7 top, 12b–c). On the average, in faster-growing plantigrades the first ridge appears at a shell length of about 250 μ (Fig. 12a). In all, some four to twelve of these form on different individuals, but considerable variation in the number is apparent for a given size of clam. What determines the final number of these ridges is unknown. Because of the soft composition of the primary ridges, they soon erode, making them difficult to count on individuals under 10 mm. in length except on well-preserved specimens.

The deposition of a second set of lamellations (the secondary shell ridges) begins at a shell length of about one millimeter and coincides with early stages of development of the definitive exhalant siphon (Fig. 7 top, 10, 12d–e). These ridges are set more widely apart and are many times higher and thicker than the primary ridges; they are characterized by a translucent white color and are secreted periodically for the

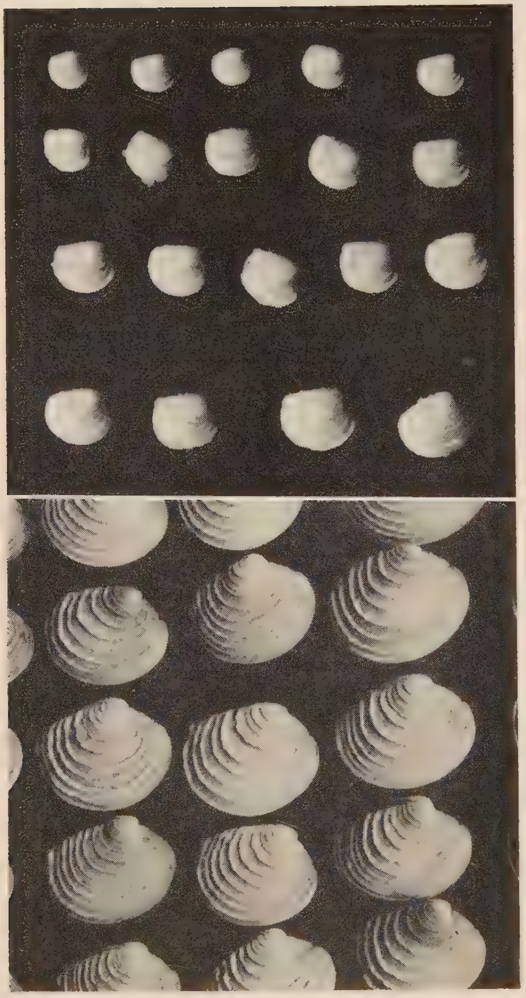


FIG. 7. Top, photomicrograph of byssal plantigrades of *M. mercenaria* ranging in length from 1.7 to 3.2 mm., illustrating the low, close-set primary shell ridges and the first two to five prominent, widely set secondary shell ridges; 3X (photomicrograph by T. C. Nelson and H. H. Haskin). Bottom, photomicrograph of juvenile plantigrades of *M. mercenaria* ranging in length from 11 to 13 mm., 1.5X (photomicrograph by T. C. Nelson).

duration of shell formation in the species. Secondary ridges are considerably harder than primary ones and consequently do not erode so readily.

In the summer of 1949 we made a study of the number and rate of formation of secondary shell ridges on the valves of byssal plantigrades. Fifty native young were collected locally in Little Egg Harbor, and fifty laboratory-reared hard clams were contributed by Dr. Loosanoff. Individuals of both populations were placed in sediment in small glass dishes in a protected enclosure secured to the side of the "Cynthia," which was moored in Thompson Creek, and examined periodically through the summer. When first collected and established in the enclosure the clams ranged in length from one to four millimeters. The number of secondary ridges on plantigrades of various lengths observed at intervals during the summer is given in Figure 8. There is a general tendency for larger clams to possess more ridges, but the number of ridges on different individuals of the same size is exceedingly variable. For example, the number of ridges in individuals in the length bracket 3.0 to 3.5 mm. varied from four to twelve; and a total of six ridges was found in a sample of individuals ranging in length from 1.0 to 4.6 mm. The number of ridges borne by laboratory-reared and native populations did not vary significantly.

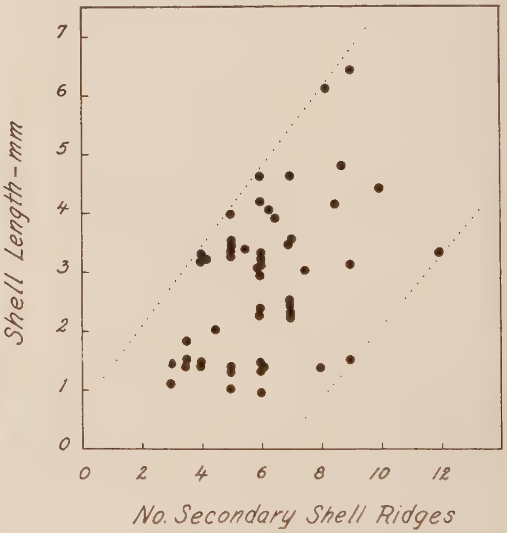


FIG. 8. Correlation of number of primary shell ridges with shell length in byssal plantigrades of *M. mercenaria.*

FOOT AND LOCOMOTION. The foot develops in the late veliger stage as a long, rounded, slender, heavily ciliated, highly supple, extensible organ (Fig. 6). We have seen functional feet in pediveligers as small as 166 μ in length. In clams 235 μ in length the foot may be extended normally about 190 μ beyond the ventral margins of the valves; this extension may be about 350 μ beyond the valves in individuals 415 μ in length, or 9 mm. in specimens 7 mm. in length (Figs. 9, 10). Inside the mantle cavity the foot may be turned 180° and protruded rearward, and after the foot contacts the substratum the body realigns itself over the

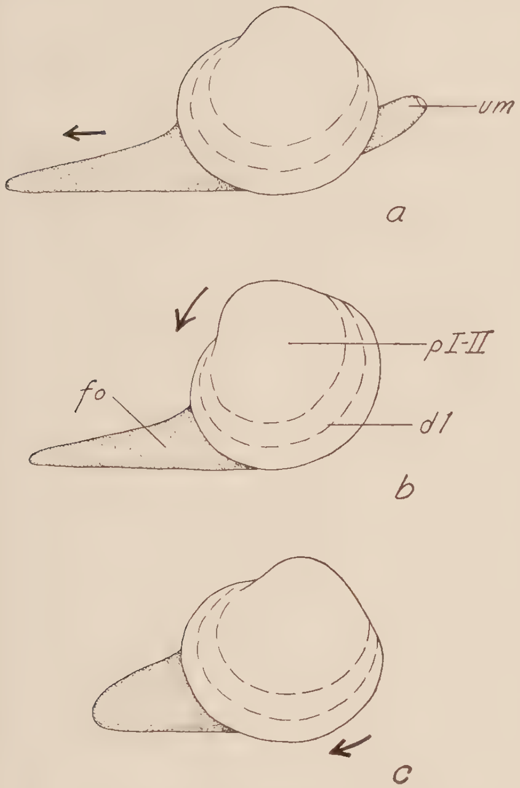


FIG. 9. Illustration of the mode of locomotion in a byssal plantigrade of *M. mercenaria*, 415 μ long, 80X. d1, dissoconch primary shell ridges; fo, foot; pI and pII, prodissoconchs I and II; vm, valvular membrane.

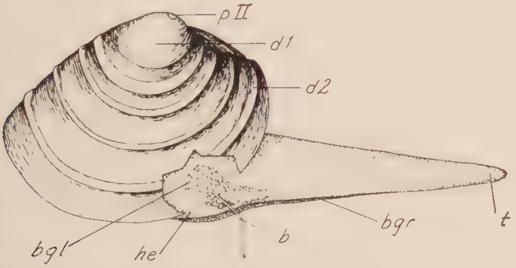


FIG. 10. Detailed drawing of byssal plantigrade of *M. mercenaria*, 4 mm. long, 10X. Portion of left valve cut away to show position of byssal gland in heel of foot. b, byssus; bgl, byssal gland; bgr, byssal groove; d1, dissoconch primary shell ridges; d2, dissoconch secondary shell ridges; pII, prodissoconch II; t, foot.

foot. On an open surface lacking sediment, clams often extend the foot under themselves and turn themselves over. As the plantigrade animal grows, the foot becomes shorter in proportion to the size of the shell, and the base of the foot becomes stockier.

Pedal locomotion in pediveligers and newly set plantigrades principally involves ciliary activity: cilia on the ventral surface of the foot beat toward the heel of the foot, so that the foot and animal glide forward smoothly over the substratum. Similar locomotion has been described by Quayle (1952) for planktonic veligers of *Venerupis* which have gained use of a foot. This type of movement is soon superseded in part by a muscular, crawling type of locomotion which is particularly well suited to movement through sediments and which is retained for the remainder of the animal's life. Crawling by byssal plantigrades about 0.4 mm. in length on hard, open surfaces is characteristic of all sizes of animals in this stage and agrees generally with the description given by Belding (1912) for crawling by *M. mercenaria* 2 to 3 mm. in length. It is performed in the following manner: from the resting position on one valve, a clam extends the foot anteriorly between the margins of the valves and effects contact with the substratum, the forward tip, or toe, of the foot acting as a searching and guiding organ (Fig. 9a). The mid-portion of the foot is then appressed to the substratum, flattened to one and a half times its normal width; the area of contact passes distad until the whole distal half of the foot is appressed and purchase with the substratum is effected. During this maneuver the clam draws its valves upright and pulls them forward over the foot by contraction of pedal muscles. If the foot, when first extended, strikes an object, it withdraws again within the mantle cavity and extends anew in a different direction, moving by means of ciliary and muscular-vascular action. Occasionally the valves fall again to one side but are soon righted. With each forward prolongation of the foot, the clam opens its valves slightly, and the mantle margins of the pedal opening maintain a close seal around the foot to exclude sedimentary grains as the foot is withdrawn; it simultaneously everts the exhalant valvular membrane (Figs. 9a, 12b–d). Upon initial contraction of pedal muscles, the valves close gently upon the foot and the valvular membrane is withdrawn completely (Fig. 9b); anterior portions of the valves are pulled toward the substratum (Fig. 9b), and immediately following this action ventral portions of the shell are drawn forward (Fig. 9c) over the foot as the foot contracts. The over-all effect is that of a bivalve moving forward by rocking its shells over the foot, the ventral rims of the valves sliding over the bottom much as a sled moves on its runners. The foot adheres to firm substrates with great tenacity.

Clams express much the same type of locomotory activity when crawling through sediments. A pointed toe (Fig. 10) extends into the sediment and then expands, forming a partial anchor; then the foot contracts and draws the body over it. Clams are capable of pushing aside, or crawling under, grains of sediment several times the size of their bodies. Digging movements in young *M. mercenaria* resemble those described for young *Venerupis pullastra* by Quayle (1952), except for protrusion and use of the heel of the foot in digging by *V. pullastra*.

BYSSUS AND BYSSAL ATTACHMENT. Belding (1912) was the first to report that young *M. mercenaria* possess a byssus. Shortly after larvae of *M. mercenaria* assume the plantigrade habit, and sometimes before the velum is lost, the byssus gland becomes functional and the bivalve begins attachment to substrata by means of a transparent, somewhat elastic thread, the byssus (Feen, 1949). The byssus gland occupies a major portion of the heel of the foot (Fig. 10). Fluid byssal material passes from the gland through the byssal duct to the midventral base of the foot, where it flows into the byssal groove. This is a longitudinal depression along the midventral surface of the basal two-thirds of the foot. The groove shallows as it passes distally from the heel, and its edges, which form prominent folds in the vicinity of the heel, also diminish in size distally. Kellogg (1892) illustrates and describes the histology of the byssal gland in the carditid bivalve *Venericardia borealis*. The secreting epithelium is deeply folded, and at the inner ends of the folds many muscle fibers are strongly inserted and serve by their attachment to the valves dorsally as a powerful support for the byssus. No such studies have been reported for *M. mercenaria*. Young hard clams effect initial fixation to the substratum or to grains of sediment by means of a very fine transparent byssus scarcely visible at a magnification of 70X. As the clam grows the byssal gland, duct, and groove continue to develop. In individuals 270 μ in length the byssus possesses a maximum diameter of 5 μ and a length of about 0.3 mm., though the length is extremely variable; in an individual 400 μ in length, the byssus is 8 μ in diameter; in one 6 mm. in length, 30 μ in diameter and up to 4 mm. long to the first holdfast, and may extend through a number of holdfasts to a total length of 2 cm. (Fig. 11). By the time a clam reaches a shell length of 0.5 mm., the byssus is a sturdy anchor line; and at shell lengths ranging from 0.5 to 1 mm., clams adhere so firmly to hard surfaces by means of the byssus that a strong stream of water directed at them from a bulb pipette does not dislodge them. The longest byssus encountered proportionate to the length of the shell was 5.5 mm. in a clam 1.4 mm. long. We were not able to determine the range of lengths at which clams lose use of the byssal gland; a gross estimate of the average length is about 7 mm. Belding (1912) reports finding a byssus in a clam 9 mm. long.

We made the following observations of byssus formation and attachment: A binocular microscope was secured in an inverted position on a cantilevered support under a small petri dish lighted from beneath by a strong spot light. Clams ranging in length from 0.5 to 7 mm. were placed in shallow dishes with a small quantity of fine beach sand and clean sea water. Light did not appear to disturb the mollusks so long as they remained buried in the sediment. This device permitted the observer, lying in a steeply angled swivel chair under the microscope, to follow movements of plantigrades at various magnifications as they crawled about in the dish and effected byssal attachment. Observations were made in both New Jersey and in North Carolina on individuals of several populations of active, fast-growing, laboratory-reared *M. mercenaria*.

Clams anchored the byssus on an open surface but made attachment more quickly and frequently when completely buried under sediment. (We used the vital stain neutral red in preliminary observations to demonstrate the byssus more clearly, but the stain tended to inhibit attachment and therefore was discarded.) In the process of attachment under these laboratory conditions a clam extends the foot slowly, moving the foot through the sand with the toe held close against the substratum. At full extension of the foot the toe is pressed firmly against the substratum for a period varying from 0.5 to 3 seconds. During this action, edges of the byssal groove meet midventrally, converting the byssal groove into a tube, and minute peristaltic waves pass along the foot, this probably presses byssal fluid along the byssal tube, since formation and fixation of the byssus is too rapid to be effected by ciliary action alone. After attachment of the byssus to the substratum, the foot is withdrawn slowly (at the same rate as when crawling) within the mantle cavity, paying the byssus out behind it. The actual attachment, or holdfast, of the byssus on the substratum is a hardened drop of byssal fluid. Probably upon contact with sea water, this hardens quickly, as indicated by the fact that the byssus holds against a stream of sea water from a small pipette within less than a minute after attachment. Following affixation, the clam may withdraw the foot completely within the mantle chamber and close the valves upon the byssus; or it may remain open, siphoning interstitial sea water under the sediment; or it may crawl to the surface of the sediment to siphon, still held by the byssus; or it may secrete a longer byssus with a number of holdfasts (Fig. 11) before becoming quiescent.

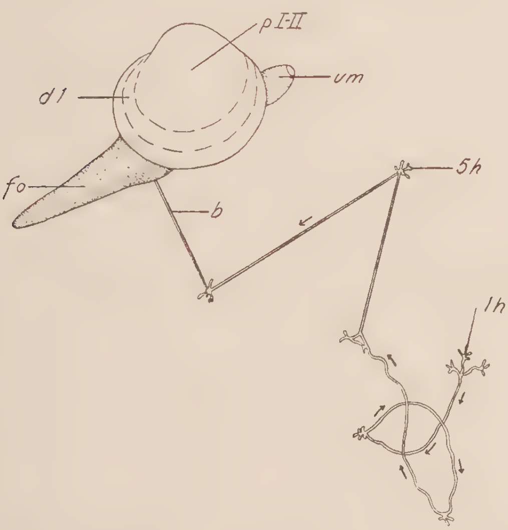


FIG. 11. Diagram of the byssal "trail" laid down by a byssal plantigrade of *M. mercenaria*, 415 μ long, in shallow sand in a finger bowl. 50X. b, byssus; d1, dissoconch primary shell ridges; fo, foot; pI-II, prodissoconchs I and II; vm, valvular membrane; 1h, first holdfast; 5h, fifth holdfast of byssus.

The holdfast is usually characterized by a distinct digitate blob of byssal material, frequently containing sand grains trapped in the byssal fluid as the holdfast is molded against a sand-covered firm surface. The small size of the holdfast (Fig. 11) suggests the degree of confinement afforded the hardening byssal fluid by the pedal tip at the moment of attachment. The complexity of the sample byssal trail illustrated in Figure 11 directs attention to the considerable versatility and maneuverability of the byssal groove and foot during placement of successive holdfasts.

In deep sediment clams affix the byssus to several grains of sediment a short distance under the surface and then move surfaceward, assuming a position, depending upon the length of the siphons, on or just under the water-sediment interface. In a dense population of byssal plantigrades, byssuses form a loose mat of interwoven threads.

Clams may also affix by means of a forked byssus, though actual formation of this was not observed.

Removal of sediment from about byssal plantigrades causes them to release the byssus at its insertion in the byssal duct, move to another site, and there reaffix. In discarding the byssus, young plantigrades crawl forward effortlessly, easily dropping the byssus and holdfast behind. Those approaching a shell length of 300 μ may make two or three attempts, circling about, resting occasionally, pulling tightly against the holdfast, until the byssus is dislodged from the byssal duct. A clam two millimeters in the branching ducts of the byssal gland it-at the holdfast for a minute or so before crawling away. One such individual, in detaching the byssus, crawled slowly and with apparent effort from the holdfast over a period of 5 minutes, stretching the byssus to a length of 5.5 mm. before it gave way, contracting onto the substratum like a rubber band. Whether the byssus is held in the duct by a sphincter muscle or by hardening of the byssal branches in length may turn about on its foot and tug self is not known. Probably the closed valves further aid in securing the byssus to the animal.

In the laboratory the interval between disturbance and reattachment of different individual byssal plantigrades varied from a few minutes to several hours. We made this observation in North Carolina in August, 1956, on laboratory-reared clams ranging in length from 0.9 to 2.4 mm. These animals were maintained in running, sand-filtered, sea water and fed a supplemental diet of mixed algae. Twenty clams were placed in each of 10 petri dishes 5 cm. in diameter with a little heap of fine beach sand and fresh sand-filtered sea water (salinity 35.5 $^{0}/_{oo}$). Clams and sand were swirled into the center of each dish and the dishes set aside under glass covers. No artificial aeration or food was provided during the observations. Room temperature during this period varied from 23°C. in the morning to 30°C. in the late afternoon. At varying intervals of time (Table III), clams which had affixed were exposed by gentle flushing aside of the sand in each dish with a stream of sea water from a bulb pipette. The rate of attachment is recorded in Table III. In a

Table III

Rate of byssal attachment by *M. mercenaria* in the laboratory.

Interval clams undisturbed in sand, mins.	Percentage of clams attaching during this interval
5	5
10	7
15	17
20	19
30	48
40	32
50	42
60	39
120	32
180	60

second experiment under similar conditions of salinity and water temperature, 150 clams similar to those employed in the experiment reported in Table III went uninterrupted for eighteen hours. Ninety-one per cent of these made byssal attachment, indicating that in a longer period, most of the clams did attach. Under other less carefully controlled conditions on Gardiners Island attachment of laboratory-reared clams took place more rapidly, a reaction probably more accurately representing that in nature.

Byssal attachment is not an uncommon means by which young bivalves anchor themselves to the substratum and thereby remain closer to the general area of setting (*Mytilus edulis,* Kellogg, 1892; *Mya arenaria,* Kellogg, 1901; *Hiatella gallicana,* Hunter, 1949; *Venerupis pullastra,* Quayle, 1952; *Lasaea rubra,* Morton, 1960). This is the first description of the process in *M. mercenaria.*

MANTLE FUSION AND SIPHONS. In newly metamorphosed asiphonate individuals of *M. mercenaria,* margins of the mantle lobes are free, and they part as the valves gape to permit both movement of sea water through the mantle cavity and extrusion of the foot. At a shell length varying in different individuals from about 210 to 300 μ, the inner folds of the posterioventral portions of the margins of the mantle lobes fuse over a short distance; this forms a tissue union, the siphonal septum, which divides the over-all gape into an exhalant and a combination pedal-inhalant opening (Fig. 12a). The latter functions in the intake of water and as an opening for pedal activity. We are basing anatomical terminology for *M. mercenaria* on that developed by Yonge (1957) in his study of mantle fusion in lamellibranchs. From the rim of the exhalant aperture thus formed, there soon emerges a very thin, transparent, pliable, tapering sleevelike tube, the valvular membrane (Fig. 12b), which is an extension of the inner folds of the mantle lobes and controls and directs the exhalant current. Minute particles passing out of the mantle cavity through the valvular membrane, which now accommodates the excurrent flow of sea water from the mantle cavity, are easily visible through the walls of the membrane. As the clam opens its valves to pump sea water, the membrane billows outward rapidly, forced by pressure created within the mantle cavity through ciliary activity, the distal tip unfurling from within. When hydrostatic pressure is momentarily cut off by constriction of the inhalant siphonal membrane (also see Sellmer, 1959) across the internal base of the siphon, or by the meeting of the mantle margins with no change in volume of the mantle cavity, the valvular membrane collapses into a shrunken, wrinkled tube which dangles externally. More frequently, the membrane when not functioning is inverted swiftly within the mantle cavity, distal tip first, possibly as a result of the apposition of the mantle edges concurrently with slight enlargement of the mantle cavity. Belding (1912) briefly describes and illustrates the membrane in young *M. mercenaria* and was probably the first to report it in this species.

During growth of byssal plantigrades to a shell length of about 1.5 mm., the valvular membrane continues to enlarge (Table IV), though the ratio of shell length to length of membrane in different individuals of the same size is quite variable. Thereafter, between shell lengths of approximately 7 to 20 mm., dimensions of the membrane decrease in proportion to the size of the animal as the animal grows. Eventually the membrane is reduced to a shallow flange at the tip of the definitive exhalant siphon just inside the circle of siphonal tentacles (Fig. 12b–g). Particularly during its more prominent stages, the valvular membrane is characterized by flexibility and by a relatively small distal orifice which reduces the diameter of the exhalant siphon to a fraction of that of the inhalant siphon (Fig. 12e–g).

Shortly after the genesis of the exhalant valvular membrane, two small truncated tentacles, forerunners of the ring of sensory ten-

Table IV

Ratio of length of shell to length of valvular membrane in ten young plantigrade *M. mercenaria* selected at random for measurement.

Shell length, μ	Length of valvular membrane, μ	Ratio of length of shell to length of valvular membrane
230	50	4.6
290	—	
330	100	3.3
415	200	2.1
625	380	1.6
1000	780	1.3
1360	615	2.2
1500	1500	1.0
4000	1420	2.8
14000	1100	12.7

tacles which will adorn the distal rim of the inhalant siphon, appear anteroventrad the base of the valvular membrane (Fig. 12b). Then two more tentacles form anterior to the first pair. Simultaneously the anterior portion of the fused mantle splits at the site of the inhalant siphonal opening (Fig. 12c); this makes possible conjoining of inhalant and exhalant siphonal walls as they develop. At this time a single tentacle appears dorsal to the base of the valvular membrane, the first of a ring of tentacles which will bound the distal opening of the definitive exhalant siphon. Tentacles continue to form anteroventrad the site of the first ones as definitive inhalant and exhalant siphons develop (Fig. 12d). By the time the two siphons are visible beyond the margins of the shells, inhalant and exhalant tentacles from complete rings on the distal orifices of the siphons (Fig. 12e), and the valvular membrane, now projecting from the inside base of the border of tentacles, is borne on the distal end of the lengthening exhalant siphon.

Before the appearance of the inhalant siphon, water is drawn into the mantle cavity through the inhalant-pedal opening, and the clam remains at the sediment-water interface with mantle margins in contact with ambient sea water. As siphons form, the animal begins to burrow shallowly in the sediment, siphons upward. It moves deeper as siphons lengthen, and eventually the entire shell disappears within the sediment. Direct contact with overlying sea water is maintained by siphons extending to or shortly above the surface of the sediment; or contact may be indirect through interstitial water when siphons are held beneath the sediment. Yonge notes (1957) that formation of siphons was a matter of major significance in the evolution of bivalves, enabling them to live in the shelter of a soft substratum. Clearly this step in its evolution has permitted *M. mercenaria* to survive abundantly in spite of its numerous predators.

In *M. mercenaria* the siphons are of type B, according to Yonge's (1957) classification, in which the combined siphons are formed as extensions of inner and middle folds of the mantle margins. Like the valvular membranes, siphonal tentacles are also derived from the inner fold of the mantle margins. Mantle fusion and siphon formation in *M. mercenaria* resemble rather closely that described briefly by Quayle (1952) for the venerid clam *Venerupis pullastra.*

Arrows in Figures 12a–g indicate direction of flow of sea water through the mantle cavity. In asiphonate byssal plantigrades restricted to lying or crawling on the surface of sediments, the ventral margins of the mantle lobes separate slightly to permit ingress and egress of sea water, the region of inflow occupying more than half of the length of the gape. Initial fusion of the mantles at the siphonal septum restricts egress of water to the posterior or exhalant opening. As the inhalant siphon forms, it becomes the principal course of entry of incurrent water into the mantle cavity, and the pedal gape is utilized only occasionally.

In siphonate clams, siphon tips (including the valvular membrane) point away from each other (see especially Fig. 12f–g), thus deflecting incurrent from excurrent water. As demonstrated in hard clams 10 to 15 mm. in length in sea water containing a carmine suspension, the excurrent stream, which flows from the relatively small exhalant orifice, is characterized by a velocity and length of flow path several times that of the incurrent flow through the larger inhalant opening. As a consequence of this differential in flow, the water mass in the immediate vicinity of the siphons is moved away from the posterior end of the clam, drawn by the relatively stronger flow of the excurrent stream, and mixing of incoming and effluent water is thus much reduced. Therefore, in moving water a siphonate clam draws in little, if any, of its own excurrent water; and in still water some time may elapse before excurrent water recirculates to the inhalant siphonal aperture. The valvular membrane functions provisionally

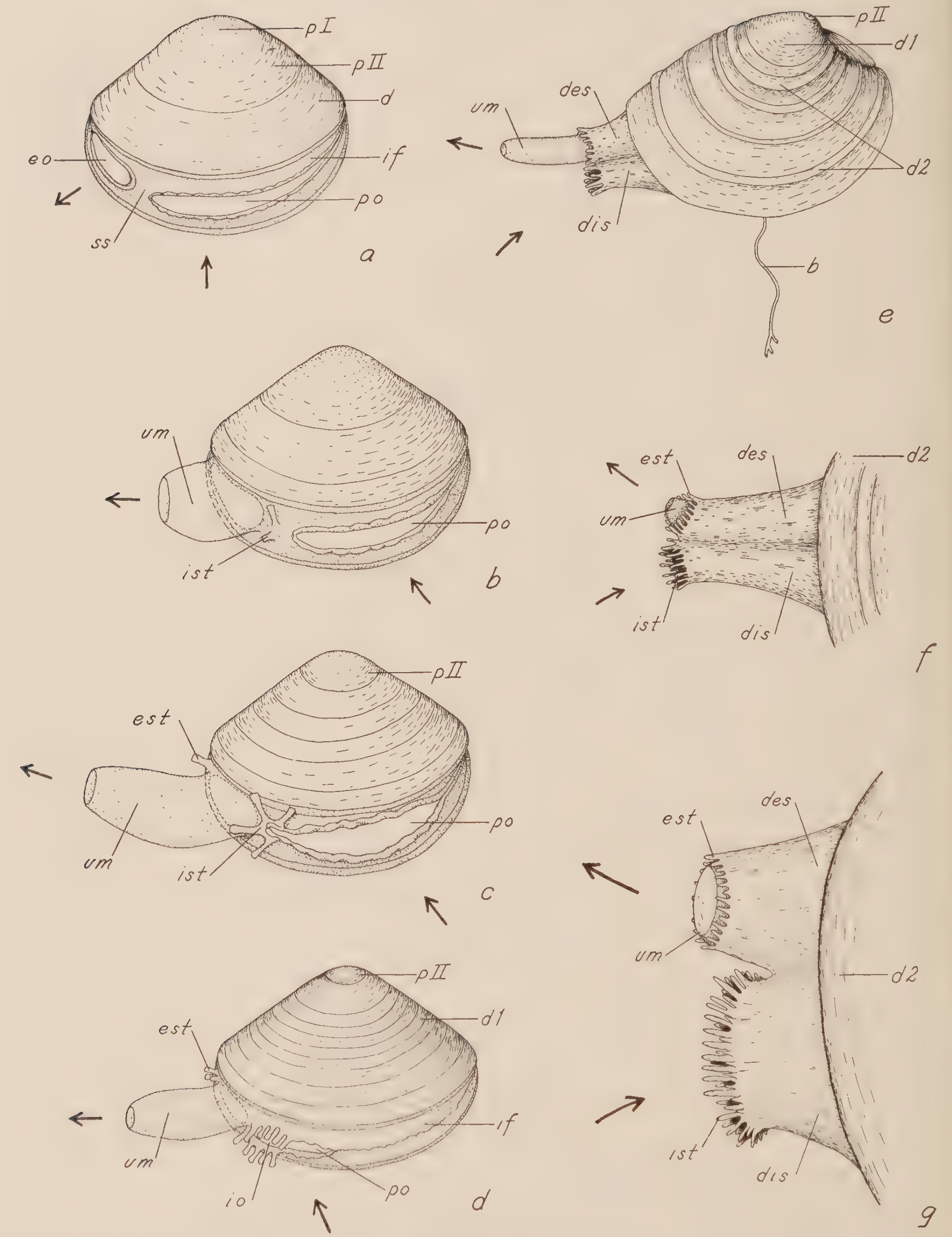

pI
pII
d
eo
if
po
ss
a
pII
d1
des
um
d2
dis
b
e
um
po
ist
b
est
des
d2
um
ist
dis
f
pII
est
po
um
ist
c
des
est
um
d2
ist
dis
g
pII
est
d1
if
um
io
po
d

FIG. 12. Detailed drawings of seven stages in the development of definitive siphons in *M. mercenaria;* arrows indicate direction of flow of water through clams:

a. Byssal plantigrade, 290 μ long, 250X. Fusion of mantle margins delimiting opening for the exhalant siphon has begun; deposition of dissoconch shell has started, and two primary shell ridges are present.

b. Byssal plantigrade, 330 μ long, 220X. Valvular membrane is forming out of exhalant opening, and two inhalant siphonal tentacles and two primary shell ridges are present.

c. Byssal plantigrade, 625 μ long, 115X. Valvular membrane is further developed; four in-

in deflecting excurrent and incurrent streams during the period of definitive siphon formation. Quayle (1952) assigns to the valvular membrane in young sedentary *Venerupis* the function of keeping the mantle cavity and gills free of feces. Newly metamorphosed *M. mercenaria* undergo a similar sedentary asiphonate stage in which, so far as can be determined, however, no fouling of surfaces of the mantle chamber occurs. Thus it would appear that in *M. mercenaria,* at least, the valvular membrane serves as a transitory exhalant siphon, insuring a decreasing rate of recirculation of mantle sea water as the clam grows and as the area of its respiratory membranes decreases relative to the increase in body volume and greater need for oxygen.

ROLE OF VALVES, FOOT, AND SIPHONS IN BURROWING. The activity of byssal plantigrades within sediments was observed under low magnification in small sediment-filled glass cells. Open rectangular receptacles which were constructed of glass plates and were slightly wider internally than the width of young clams were filled with fine, muddy sand and sea water and secured openside up against the stage of a binocular dissecting microscope held in a horizontal position. Clams, confined loosely between the sides of the cells, moved up and down readily and could be followed closely through the microscope, illuminated by direct light from a laboratory window. Sea water in the cells was changed frequently. Some clams were dropped on the surface of the sediment and observed as they buried themselves, and others were placed deep in sediment and watched as they moved surfaceward. Observations were made principally on Gardiners Island in prevailing summer salinities and temperatures there.

In burrowing, the clam extends the foot downward out of the mantle cavity, lengthening it to a long, slender, tapering organ which readily worms its way among the grains of sediment. At the maximum extension of the foot the distal tip distends, providing a partial anchor in the sediment against which the remainder of the foot pulls as it contracts and draws the anterior end of the clam downward into the sediment. Immediately after, the clam draws its posterior end downward and forward, the direction of movement of the valves more or less paralleling the direction of the concentric shell ridges. In this manner these ridges offer minimum resistance to progress of the valves through sediment; yet after the clam becomes stationary, the ridges, because of their size and curvature, themselves aid in anchoring the whole animal in the sediment. The seesaw movement of the valves continues until the clam has completely buried itself. In loose sediment a byssal plantigrade can bury itself in a half-dozen seesaws in less than a minute.

When coming to the surface a byssal plantigrade forces itself upward out of the sediment with the foot; it moves slowly and intermittently, more or less posterior end first, and omits the seesaw movements of the valves. If siphons point in some other direction, the clam reorients itself upside down. The foot extends slowly, pressed firmly against the sediment; it withdraws to variable lengths, rests for several seconds, and then extends anew to push the body further up. The entire maneuver is an un-

---

halant siphonal tentacles, one exhalant siphonal tentacle, and five primary shell ridges are present.

d. Byssal plantigrade, 1.36 mm. long, 55X. Valvular membrane is further enlarged; ten inhalant siphonal tentacles, three exhalant siphonal tentacles, and ten primary shell ridges are present.

e. Byssal plantigrade, 4 mm. long, 20X. The valvular membrane has been carried outward on the distal end of the definitive exhalant siphon as the latter developed, and the inhalant siphon has formed alongside and fused to the exhalant siphon. Numerous tentacles are present on the distal margins of both siphons. The byssus extends ventrad between the valves, and four secondary shell ridges are present. Prodissoconch and dissoconch valves with primary shell ridges are illustrated diagrammatically as smooth shell surface.

f. Siphons of juvenile plantigrade 14 mm. long, 4X. Siphons are fully formed, and the valvular membrane has been reduced to a short, funnel-shaped outlet.

g. Definitive siphons of adult, 55 mm. long, 4X. Siphons extend only slightly beyond the margin of the valve, though they many be extended very much farther (see Fig. 13), and the valvular membrane is now reduced to a short shelf just inside the tentacular border of the exhalant siphon.

b, byssus; d, dissoconch; des, definitive exhalant siphon; dis, definitive inhalant siphon; d1, dissoconch with primary shell ridges; d2, dissoconch with secondary shell ridges; eo, exhalant opening; est, exhalant siphonal tentacle; if, inner fold of mantle; io, inhalant opening; ist, inhalant siphonal tentacles; po, pedal opening; pI, prodissoconch I; pII, prodissoconch II; ss, siphonal septum; vm, valvular membrane.

hurried one, and there is no indication of distress. Byssal plantigrades can emerge from sediment through a depth of at least five times the shell length, and adult clams buried by sediment from human channel-dredging activities can move upward through at least a foot of loose, sandy mud at summer temperatures.

When crawling in sediment, the byssal plantigrade continues to pump water, though at a reduced rate which apparently corresponds with the porosity of surrounding sediment. Tentacles on the inhalant siphon fold inward, forming a partial screen which admits water and small particles but excludes the larger sedimentary grains. As the screen becomes blocked by larger particles, the clam appresses its valves slightly but forcefully, emitting spurts of water principally out the inhalant siphon. The force of these jets of water is considerable. For example, a clam three cm. in length buried in sediment with siphons extended just out of shallow water can jet a stream of water across an aerial trajectory some 30 inches from the inhalant siphon. In clams submerged in sediment, these jets clean the inhalant siphonal screen, and they also tend to clear a small sediment-free space in front of both siphons into which the siphons can then distend. The exhalant valvular membrane and siphon do not function in clearing a path for the clam through the sediment by discharging water, but in a limited way as permitted by confinement of surrounding sediment they do divert incurrent from excurrent siphonal streams of water. As the clam approaches the surface, siphons many extend to the surface and siphon actively, or may pump interstitial water just beneath the surface of the sediment. In Delaware Bay, New Jersey, Dr. T. C. Nelson (personal communication) occasionally observed only single excurrent streams of sea water bubbling from young clams in the sand, indicating that incurrent water was being drawn interstitially through the sediment. More commonly both siphons communicate directly with water at the surface.

Clams can extend the siphons beyond the margin of the valves to a length at least twice that of the valves. A series of measurements of siphon lengths in clams ranging in length from 5 to 35 mm. under conditions of low oxygen tension in trays and in jars (Fig. 13) established a range of ratios of length of siphon to length of shell of 1.0 to 2.3. The degree to which siphons may be extended normally in sediment in the native habitat is not known. Because of the capacity of *M. mercenaria* to siphon within porous sediments, short siphons do not impose a limit on the depth to which the animal can burrow. In the field in the summer we have found young clams buried in sediment as much as five times the shell length; and T. C. Nelson (personal communication) reported finding the ventral margins of adult clams eight to ten inches below the surface of the botton in Delaware Bay in late November winter conditions.

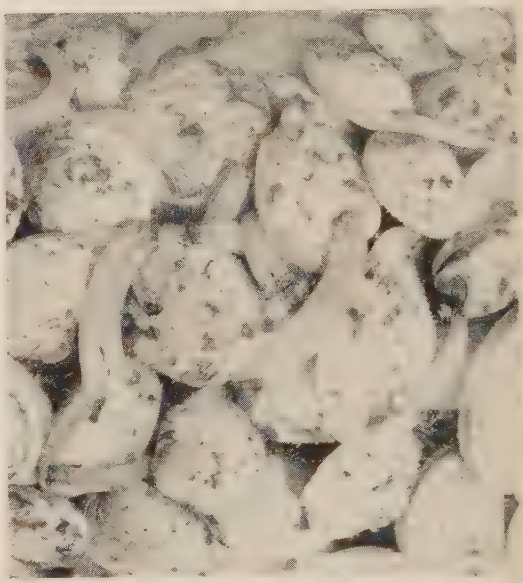


FIG. 13. Definitive siphons of adult *M. mercenaria,* shells ranging in length from 5 to 6 cm., and siphons fully extended in deep jar under conditions of low oxygen tension. 1/3X.

Thus in nature young plantigrade *M. mercenaria* are well endowed for an existence of vertical adjustment to fluctuating bottom levels in unstable bottoms of channels and inlets where they commonly occur in abundance. It is probable that young byssal plantigrades cannot burrow until the ring of tentacles is available on the inhalant siphon as a screen to exclude sedimentary grains. Whether a change in geotactic response occurs at this time is not known.

III BEHAVIOR AND AUTECOLOGY

Planktonic Stages in the Laboratory

Trochophore and early straight-hinged stages of *M. mercenaria* are strong swimmers and tend to concentrate in the surface layers of water in culture jars. Turner and George (1955) determined that early straight-hinged veligers, when held at a temperature of 22°C., swam upward at a rate of from seven to eight centimeters per minute, showed no detectable reaction to light, and were indifferent to a considerable range of salinity gradients. These investigators introduced larvae into the bottom of a glass tube in which layers of diluted sea water were placed one above the other. The larvae passed through the sharp transitions separating layers which differed by as much as 5 $^{0}/oo$ with no loss in velocity until the gradient between 20 and 15 $^{0}/oo$ was traversed. At the latter stratum swimming velocity decreased and larvae swam slowly in circular patterns just above the 20–15 $^{0}/oo$ interface.

Late straight-hinged and early umboned veligers continue to be vigorous swimmers and tend to remain uniformly distributed in culture jars. They swim in slow, circling movements propelled by the ciliated velum projecting between gaping valves. When pipetted into a watch glass, some veligers remain on the bottom with valves closed momentarily while others swim immediately and actively about, a few so swiftly that they are difficult to follow under a magnification of 35X. In swimming off the bottom, some individuals spread the valves, extend the velum quickly, and swim hinge line first in spiraling paths; then they may suddenly reverse direction and swim velum first; others swim velum first directly off the bottom, sailing majestically surfaceward.

We confirm the observations of Turner and George (1955) that even when crowded to densities of fifty larvae per cubic centimeter, the larvae seldom collide with each other, for "the currents provided by the swimming organ seem to act like the slip stream of an aeroplane." In more dense cultures collisions are frequent, and some of the colliders fall toward the bottom. Those hitting the bottom frequently turn rapidly in place before swimming away.

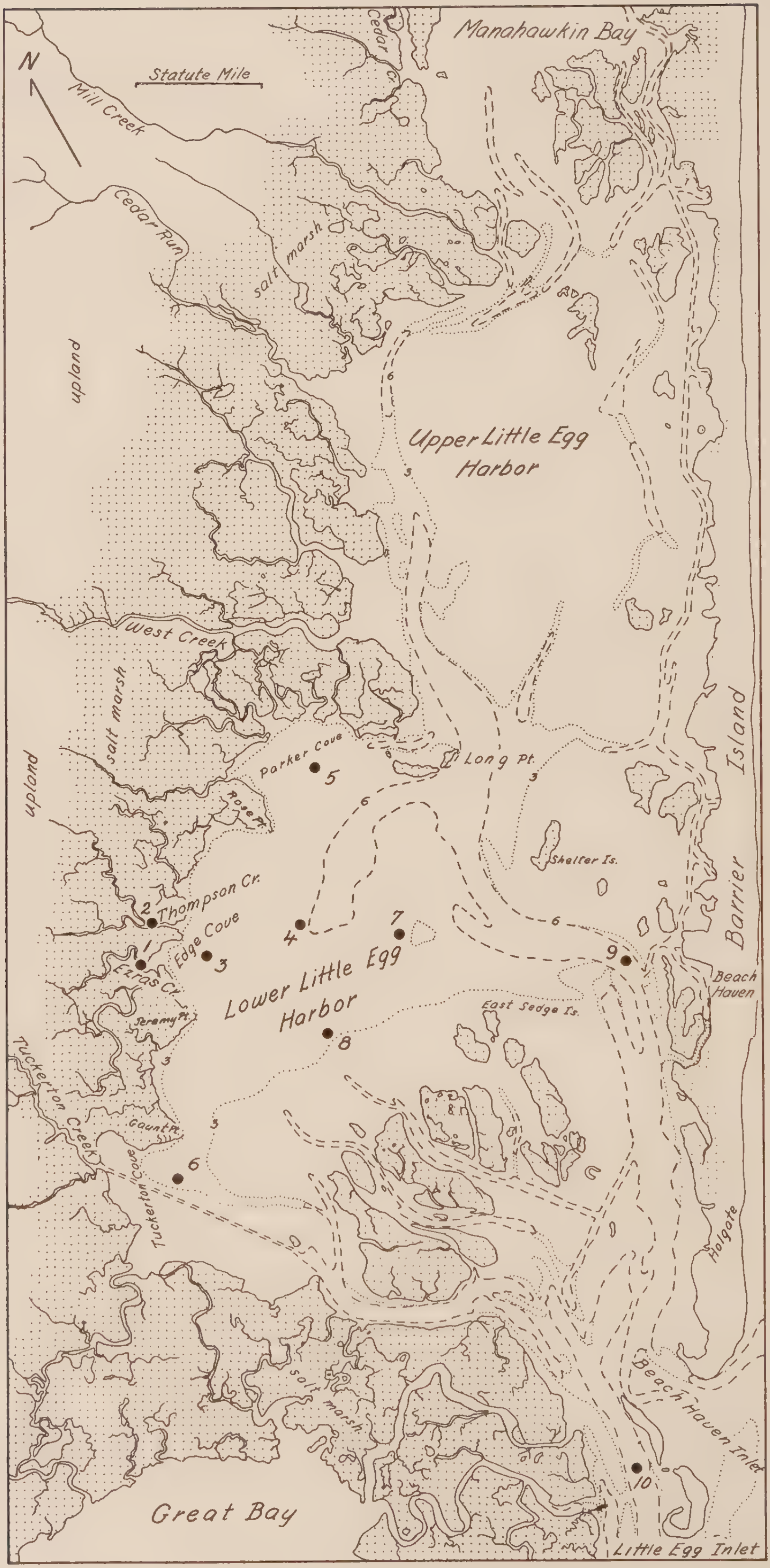
Mild pipette-driven currents of water and gentle knocks on the walls of culture containers do not bring about cessation of swimming, whereas a drop of water falling on the surface of a culture dish will stimulate larvae in the close vicinity of the splash to close their valves and sink for a short distance before they resume swimming. When they are swirled into a heap in the center of a small concave vessel, swimming veligers continue moving and soon disperse more or less uniformly throughout the water. So far as could be determined, healthy well-fed larvae never rest on the bottom of the culture containers; apparently they pass the entire veliger stage suspended in the water. Conversely, underfed larvae, or "diseased" larvae, drop to the bottom after a few days and remain there with only sporadic swimming efforts. In rearing larvae in still water in shallow open trays, we have observed that those (particularly the early stages) near the glass-water-air interface become trapped in the drying film there and may be killed by desiccation and increasing salinities.

Our fastest-growing veligers metamorphosed and started setting eight days after fertilization of the ova.

Planktonic Stages in the Field

Behavior and ecology of veligers of *M. mercenaria* were studied in two separate ecologically distinct estuaries. The first—Little Egg Harbor, New Jersey—is a large estuary characterized by dense populations of adult *M. mercenaria,* high uniform salinities, and moderate exchange and negligible flushing rates which contributed to retention of a high percentage of larvae to the setting stage. The second—Home Pond, New York—is a small intertidal arm of Gardiners Bay, and is also characterized by dense populations of *M. mercenaria,* high uniform salinities, and negligible flushing rate, but possesses exchange ratios as high as 73 per cent, so that young larvae originating within the pond are quickly transported out of it, and larvae which set in it enter on the late flood tide from the bay as pediveligers. The Home Pond studies have been published (Carriker, 1959); a report of those in Little Egg Harbor constitutes this section of this paper.

The first phase of this investigation involved study of a number of the more obvious environmental factors which might be associated with the behavior and ecology of early stages of *M. mercenaria.* Of these, morphometry, rainfall, tidal currents, water movements, salinity, and temperature were studied in detail; and wind direction and velocity, turbidity, and sediments were observed more generally. L. R. Pomeroy and H. O. Werntz aided materially in the collection of these hydrographic data.


N
Statute Mile
Mill Creek
Cedar Cr.
Manahawkin Bay
Cedar Run
salt marsh
upland
Upper Little Egg Harbor
West Creek
salt marsh
upland
Parker Cove
5
Long Pt.
Rose Pt.
Shelter Is.
2
Thompson Cr.
1
Edge Cove
3
4
7
Ezras Cr.
Lower Little Egg Harbor
9
Beach Haven
Barrier Island
East Sedge Is.
Jeremy Pt.
8
Tuckerton Creek
Gaunt Pt.
Tuckerton Cove
6
Holgate
salt marsh
Beach Haven Inlet
10
Great Bay
Little Egg Inlet

1. Hydrography of Little Egg Harbor

MORPHOMETRY, RAINFALL, AND EVAPORATION. Little Egg Harbor is a shallow coastal plain estuary of Type C (Pritchard, 1955) (Fig. 14) approximately four statute miles wide at the southwestern end and some ten miles long and possesses a water-surface area of 31.5 square miles. Upper Little Egg Harbor, with the exception of a few narrow, relatively deep channels, has a depth of one to two feet at mean low water and an area of 13.8 square miles. It extends northeastward beyond its boundary as Manahawkin Bay and beyond that as Barnegat Bay (Fig. 1). Little Egg Harbor is separated from the Atlantic Ocean by a continuous barrier island devoid of inlets except for the Beach Haven and Little Egg inlets at the southern extremity and Barnegat Inlet some eight miles northeast of Upper Little Egg Harbor. Tidal currents entering through Beach Haven-Little Egg inlets meet in the Manahawkin Bay area.

Lower Little Egg Harbor has an area of 17.7 square miles, and the deeper region (bounded by Long Point, East Sedge, and Gaunt Point) is characterized by average depths at mean low water ranging from four to seven feet. A cluster of salt-marsh islands hugs the southeastern corner of the bay; around the east of these runs a wide, deep channel, and lesser channels break through the islands and to the west of them. South of the islands, Little Egg Harbor communicates with the Atlantic by a channel about one mile in width which forks into the recently opened (1920) and relatively shallow Beach Haven Inlet, and farther south into the main and deeper Little Egg Inlet shared with Great Bay (Fig. 1). No sills are present. Maximum depth for the main channels is charted as 34 feet, but constantly shifting sands alter topography from year to year. Several small channels pass between Little Egg Harbor and Great Bay to the southwest.

Volumes of Little Egg Harbor (area delimited in Fig. 14) were determined by planimetry from U. S. Coast and Geodetic Survey Charts #825 and #826, from soundings on these charts, and from data (Table VII) on mean intertidal ranges in various parts of the bay:

Subtidal volume	4.09×10^9 ft.^{3}
Mean high-tide volume	5.88×10^9 ft.^{3}
Mean summer-spring high-tide volume (inclusive of the volume of water rising over the salt marsh above the mean high-water line, 0.25×10^9 ft^3)	6.49×10^9 ft.^{3}
Maximum summer-spring high-tide volume experienced during the summer of 1948, likewise including the volume of sea water over the salt marsh, 0.79×10^9 ft.^{3}	7.70×10^9 ft.^{3}

A marginal strip of salt marsh 0.5 to 3 miles in width, with a total area of 22.6 square miles, bounds Little Egg Harbor on the landward side. The barrier island to the southeast, ranging in width from 0.2 to 0.7 mile and composed mostly of sand, is now for the most part occupied by small towns, and there are also small towns along most of the streams in the Little Egg Harbor watershed. Despite this population, however, during the course of these studies the waters of Little Egg Harbor were free of domestic and industrial pollution.

The watershed draining into Little Egg Harbor, calculated planimetrically from New Jersey Division of Geology and Topography Atlas Sheets 32 and 33, has a total area of 77.2 square miles. This is 2.4 times larger than the water-surface area of Little Egg Harbor, and 1.4 times larger than the water-surface and salt-march areas of Little Egg Harbor combined. The watershed consists of relatively flat, sandy terrain clothed by typical pine-barrens vegetation (Buell and Cantlon, 1950) and drains into Little Egg Harbor through four streams of roughly similar size—Tuckerton Creek, West Creek, Cedar Run, and Mill Creek (Fig. 14). Salt marshes around the bay are closely dissected by shallow, meandering tidal creeks which usually terminate near the upland-salt-marsh boundary and transport little or no fresh water except during periods of heavy rainfall. Ezras Creek (used as a mooring for the "Cynthia" in 1948) and Thompson Creek (similarly used in 1949–51) are representative.

Since no data were available on the rate of discharge of fresh water into Little Egg Harbor, approximate values for runoff coefficients were obtained from available data (U. S. Weather Bureau, 1948–51; U. S. Geological Survey, 1948–51) on precipitation (Toms River Station for the Cedar Creek watershed) and rate of discharge of fresh water from the Cedar Creek drainage area, which measures 56.0 square miles,

FIG. 14. Bathymetric chart of Little Egg Harbor, New Jersey. Three- and six-foot contour lines are shown. Beyond the six-foot contour lines, depths range to a maximum of 34 feet in the main channel. (Chart traced from U. S. Coast & Geodetic Survey Charts Nos. 825 and 826.)

Table V

Computation of total volume of fresh water entering Little Egg Harbor per month during the summers 1948–1951.

Year and month	(A) Run off coefficient (cfs/sq. mi. watershed/ in. rainfall over Cedar Creek watershed).	(B) Average rainfall over Little Egg Harbor and watershed, inches	(C) Run off from Little Egg Harbor watershed into Little Egg Harbor, cfs.	(D) Evaporation from Little Egg Harbor and salt marshes, inches	(E) Average rainfall minus evaporation over Little Egg Harbor and salt marshes, inches	(F) Net volume of fresh water added to surface of Little Egg Harbor and salt marshes, cfs.	(G) Net volume of fresh water added to Little Egg Harbor from run off and rainfall less evaporation, cfs.
1948 June...	0.74	5.94	339.3	3.7	0.2	107.6	446.9
July...	0.52	3.49	140.1	5.4	−1.9	− 88.2	51.9
Aug....	0.35	9.49	256.4	4.3	5.2	242.6	499.0
1949 June...	7.30	0.28	157.8	6.0	−5.8	−278.2	−120.4
July...	0.63	2.27	110.6	6.5	−4.2	−197.5	− 86.9
Aug....	0.13	3.91	38.0	4.5	−0.6	− 27.2	10.8
1950 June...	0.51	2.47	97.2	5.3	−2.8	−135.7	− 38.5
July...	0.36	2.43	67.5	5.0	−2.8	−120.6	− 53.1
Aug....	0.24	2.64	48.9	5.1	−2.5	−117.3	− 68.4
1951 June...	0.47	4.83	175.2	5.4	−0.6	− 28.6	146.6
July...	0.40	2.62	80.9	5.8	−3.2	−150.6	− 69.7
Aug....	0.35	1.36	36.7	5.7	−4.3	−202.2	−165.5

at the Lanoka Harbor gauging station. Calculations were patterned after similar ones made by Pritchard and Bunce (1959). The Cedar Creek watershed is quite similar to that of Little Egg Harbor, and the two are only four miles distant at their closest boundaries. Based on these data, the Cedar Creek runoff coefficients provided the rate of discharge of fresh water in cubic feet per second, per square mile of drainage area, per inch of rainfall, for each of the three summer months of the period 1948–1951. On the basis of the known area of the Little Egg Harbor watershed, of observed mean precipitation over and near the watershed during the summer months, and of the runoff coefficients for Cedar Creek, we could compute the fresh-water runoff into Little Egg Harbor (Column C, Table V). Precipitation data were averaged from available U. S. Weather Bureau rainfall data at the Tuckerton, Bass River State Forest, Pleasantville, and Atlantic City stations and from precipitation data collected near the "Cynthia" starting in August, 1949 (Fig. 15: 1948–1951). In addition, from runoff data and precipitation directly on the surface of the water and salt marshes of Little Egg Harbor, and from loss of fresh water from Little Egg Harbor and its salt marshes by evaporation (based on U. S. Weather Bureau evaporation data for Pleasantville), we estimated the net volume of fresh water moving into, or out of (by evaporation), Little Egg Harbor for each of the summer months of 1948–1951 (Table V).

As Column G of Table V indicates, the net addition of fresh water to Little Egg Harbor from runoff and precipitation less evaporation varied considerably from month to month. Maximum movement of fresh water into the bay—499 cubic feet per second—took place in August, 1948 (Fig. 15: 1948). This contribution was roughly equivalent to 2.23 × 10^6 cubic feet (or 0.04 per cent of the mean high-tide volume of Little Egg Harbor) per tidal cycle of 12.4 hours; or 3.01 × 10^7 (0.52 per cent) per week, the minimum duration of the planktonic stage of clam larvae observed in Little Egg Harbor. At this rate of flow, it would take some 45 months for fresh water to replace sea water in the mean high-tide volume of the bay.

Conversely, during drier months, evaporation exceeded inflow of fresh water, bringing about a net flow of sea water into the bay. During the period of minimum precipitation—August, 1951 (Fig. 15: 1951)—a net total of 165 cubic feet per second of fresh water was lost from the bay and adjacent salt marshes by evaporation. This was equivalent to a loss of 7.40 × 10^5 cubic feet (or 0.01 per cent of the mean high-tide volume of Little Egg Harbor) per tidal cycle, or 9.99×10^6 cubic feet (0.17 per cent) per week. At this rate of net loss of fresh water, the mean high-tide volume of Little Egg Harbor would be removed by evaporation in about 150 months.

TIDES. Tide level was recorded during each of the four summers on a portable automatic tide gauge (Coast and Geodetic Survey, 1941) secured to a platform supported on braced piling stuck deep in the bottom. In Ezras Creek (Station 1, Fig. 14) in 1948 the gauge was placed in the middle of the creek seventy-five feet inside the mouth, and during the remaining three summers near the middle of Thompson Creek (Station 2, Fig. 14) 135 feet inside the mouth of the creek. In both locations protection of the gauge from wave action from the open bay permitted the production of smooth curves on the tide gauge records. It was not feasible to refer our observed tide-level recordings to a tidal bench mark; therefore each summer the recording stylus of the gauge was set at an arbitrary level which would accommodate the range of local tides but not necessarily correspond to observed tide levels of other summers. Tide-height data were used principally to relate distribution of larvae of *M. mercenaria* to tidal phenomena.

The type of tide observed in the Edge Cove area was uniformly semidiurnal, the principal variations following changes in distance and phase of the moon. The height of high water was maximal after new moon and considerably lower after full moon. Curves representing high- and low-water heights paralleled each other closely (Fig. 15: 1948–1951).

In order to facilitate comparison, even though crude, of tidal amplitudes during the four summers, we averaged observed low-water heights (read from tide records to nearest 0.05 foot) for each summer to provide mean low-water levels; these levels were considered "zero height" and other tide-level figures were equated to these common planes. The mean high water for each summer was obtained by averaging high-water levels; maximum (highest) and minimum (lowest) levels for each summer represent single observations, all similarly equated to zero mean low water. These data are summarized in Table VI. Mean amplitude of the tides over the four-summer period was 1.85 feet; and maximum amplitude, in 1948, was 3.75 feet. In the Edge Cove area, the water level rose over the edge of the salt marsh at a tide-gauge height (equated to mean low water at zero) of 2.4 feet during the summer of 1950 and 2.3 feet during the summer of 1951 (Fig. 15: 1950, 1951).

The figures in Table VI for maximum, minimum, and mean high water show a consistent decrease in height from 1948 through 1951. Total rainfall in the Little Egg Harbor area during the periods in which tidal records were collected (Table V) was as follows: 1948, 18.92 inches; 1949, 6.46 inches; 1950, 7.54 inches; 1951, 8.81 inches. This trend in amplitudes may possibly be explained in part by variation in rainfall.

Decreasing tidal amplitude from the head of Little Egg Harbor toward the inlets is given in Table VII (compare Fig. 14). All figures, except those for Edge Cove, were taken from *Tide Tables East Coast North and South America*, U. S. Coast and Geodetic Survey.

WATER MOVEMENTS. Movements of water masses in Lower Little Egg Harbor were followed principally by means of a light current cross consisting of four vanes each one-square foot in area. In operation the cross was sus-

Table VI

Tide levels, in feet, for the Edge Cove area, Little Egg Harbor, N. J., for the summers of 1948–1951. Figures for each summer are equated to a mean low-water height for that summer of zero.

Tide Level	1948 June 23–Sept. 4	1949 June 5–Aug. 31	1950 June 20–Sept. 4	1951 June 15–Aug. 28	Four-summer mean
Maximum High...	3.21	2.82	2.70	2.77	2.87
Minimum High...	0.91	0.77	0.75	0.57	0.75
Mean High.......	1.96	1.87	1.80	1.79	1.85
Mean Low.......	0	0	0	0	0
Minimum Low...	0.61	0.92	0.85	0.52	0.72
Maximum Low...	−0.54	−0.68	−0.60	−0.83	−0.66

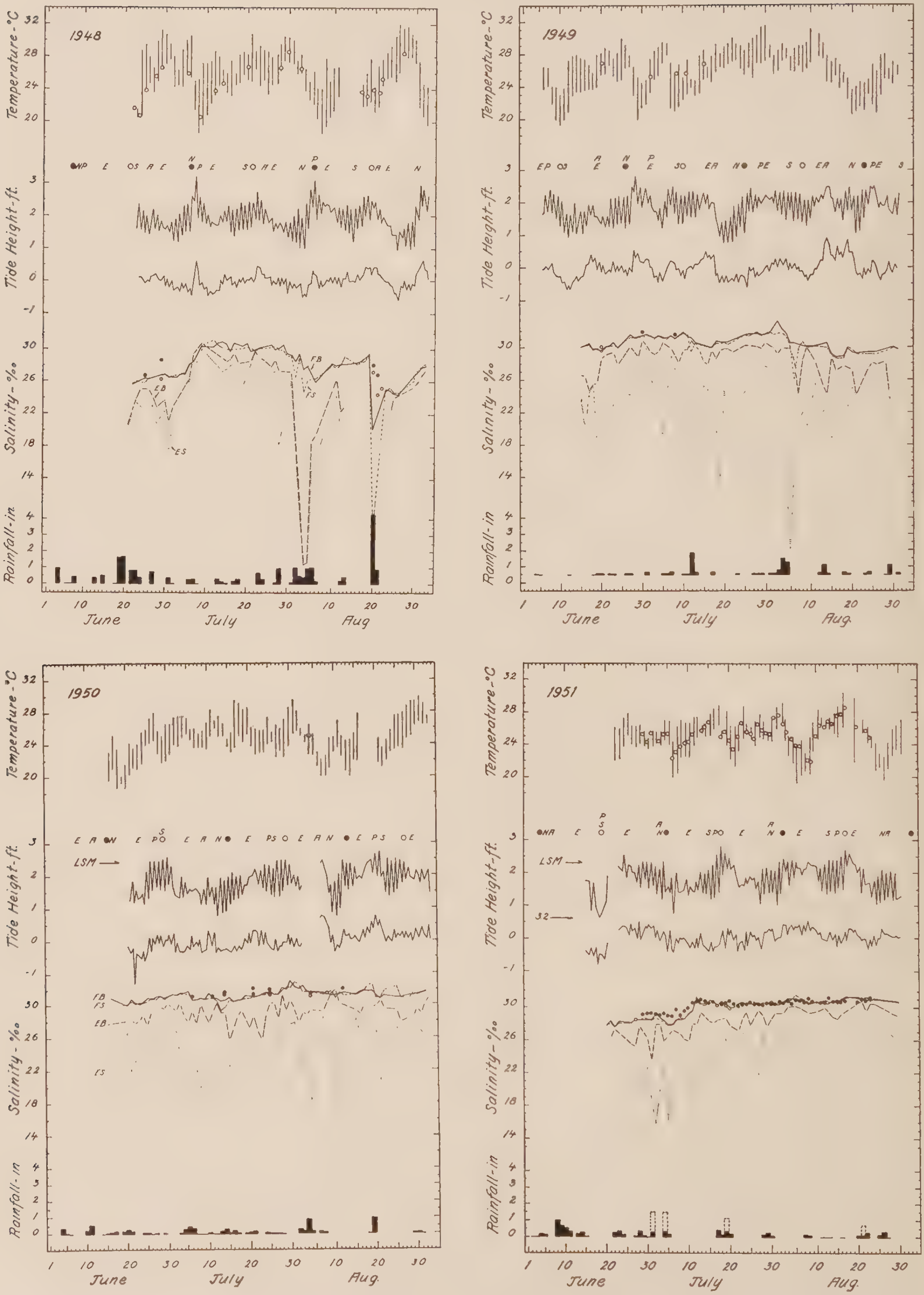


FIG. 15. Mean rainfall over Little Egg Harbor and its watershed, and tidal amplitude, salinity, and temperature of water in Ezras Creek (summer of 1948) and in Thompson Creek (summers of 1949–1951). Tide heights are equated to the observed mean low water level for the four summers of 1948–

Table VII

Mean and spring range of the tide at various points in Little Egg Harbor.

Area	Range, ft.	
	Mean	Spring
Manahawkin Bay	1.5	1.8
Edge Cove	1.8	2 1
Long Point	2.2	2.7
Beach Haven	2.2	2.7
Tuckerton Creek entrance	2.4	2.9
Holgate	2.6	3.1
Inlet (Tucker Island)	3.7	4.5

pended, the top about three feet below the surface of the water, from a small float; thus it hung about mid depth in much of the central basin of Lower Little Egg Harbor where maximal concentrations of clam larvae were encountered. The current cross was launched near low or high water in the early morning in order to obviate the effect of frequent strong afternoon winds and then followed in the laboratory powerboat as it floated from one slack period to the next. Hourly positions along the course of each run were plotted from bearings taken on fixed, charted landmarks with the aid of a magnetic compass and azimuth circle mounted in the boat. Approximately at each hourly fix, two or more vertical current velocity, temperature, and salinity observations were also made. In two of the seven tidal excursions which were followed (9–1–50 and 8–29–50, crossed circles, Fig. 16), the movement of surface water marked with fluorescein was studied simultaneously with that of deeper water by the current cross. The course of these seven runs is illustrated in Figure 16 and accompanying tidal, salinity, temperature, and current velocity data are tabulated in Table VIII.

Current velocities and directions were measured with a calibrated Ekman current meter at various depths throughout Lower Little Egg Harbor during the four summers. A composite of current patterns and maximum velocities observed during mid through late flood are presented schematically in Figure 17a, and current patterns for approximately mid ebb tide in Figure 17b. Current velocities exceeding those given in Figure 17 may have occurred, since it was not possible to measure velocities during maximal flow of the highest spring tides.

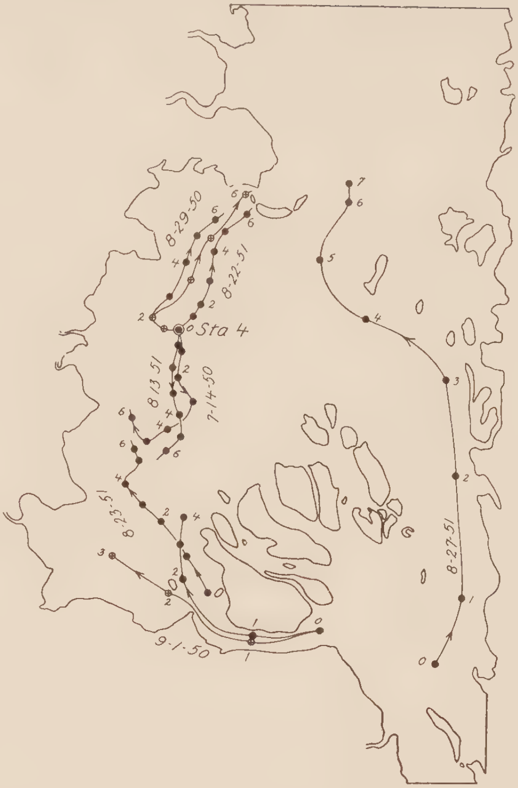


FIG. 16. Movement of water masses in Little Egg Harbor. Circles along the path of movement indicate hourly intervals, as labeled; arrows pointing up-bay indicate flooding tide; arrows pointing down-bay, ebbing tide; open circles, use of a cross suspended approximately 4 ft. below the surface of the water; crossed circles, use of fluorescein at the surface. Each tidal run is identified by the date on which the observations were made.

During early flood, sea water moving up the main channels from Beach Haven-Little Egg inlets was divided by the cluster of marsh

---

1951 (Table VI). Positions of the moon: ●, new moon; O, full moon; E, moon on equator; N or S, moon farthest north or south of the equator; A or P, moon in apogee or perigee. Salinity and temperature of the water at Station 4 superimposed over corresponding curves for salinity and temperature of water in creek (principally in 1951). Level of salt marsh at Edge Cove (LSM) is related to tidal levels (1950, 1951). Broken-line histograms over solid histograms, summer of 1951, refer to rainfall measured in rain gauge at the "Cynthia" for the Thompson Creek area when rainfall there exceeded the mean rainfall for the Little Egg Harbor watershed, indicated by the solid histograms.

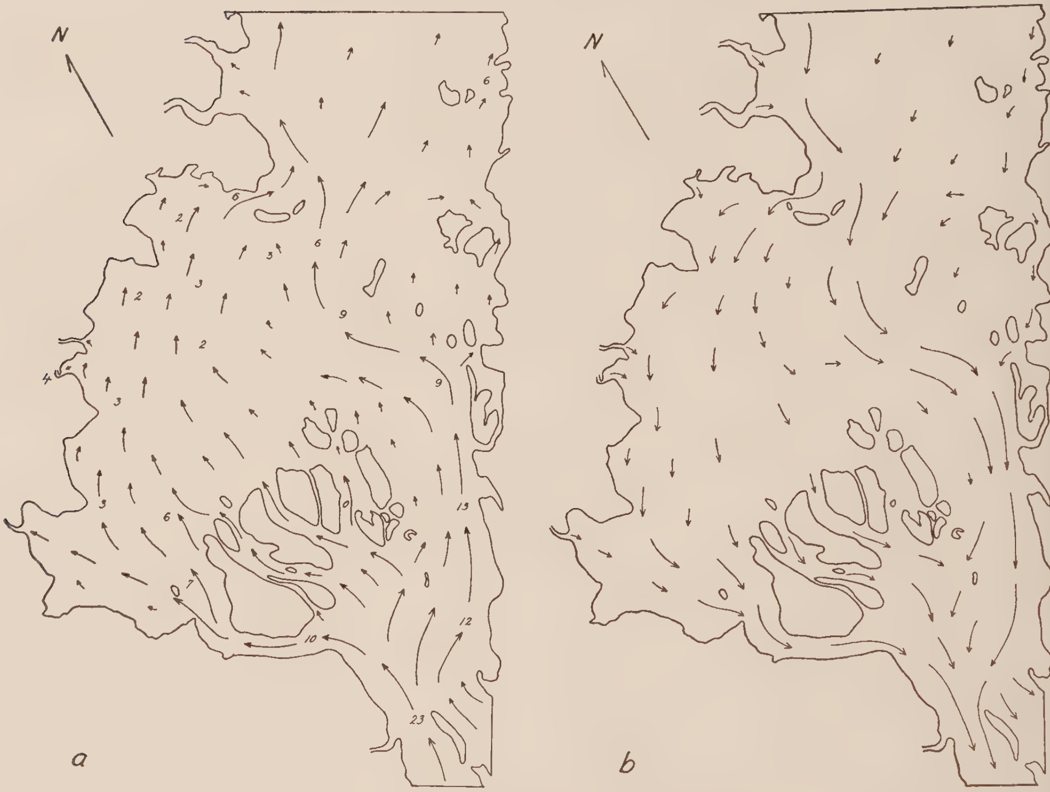


FIG. 17. a. Direction and maximum observed velocities of tidal currents in Lower Little Egg Harbor during mid through late flood tide. Length of arrows is roughly proportionate to current velocity, and numbers indicate maximum observed current velocities in ft./min. (to nearest ft.) between surface and mid depth. b. Direction of currents in Lower Little Egg Harbor during mid ebb.

islands which partially block the southern end of the bay: a small quantity flowed northwestward toward Tuckerton Creek and thence northeastward along the western shore of the bay toward Long Point; the greater volume moved northeastward along the barrier island about three miles and then swept windingly in a northward direction across the bay toward Long Point (Fig. 17a, 14). As the level of the flooding tide continued to rise, water found new passageways over shallower channels and shoals along the southern limits of the bay among the marsh islands and moved northward at the surface over deeper strata, flowing toward the center of the estuary from the southeast and southwest. The morphometry of the bay thus creates a complex circulation pattern in the central basin of Lower Little Egg Harbor where direction and velocity of currents continue to change throughout the vertical column as the tide runs its cycle. On the ebb the flows were reversed (Fig. 17b).

During low neap summer tides (tide level 1.2 feet at the tide gauge) approximately 20.4 per cent, and during mean summer high-tide periods (1.8 feet at tide gauge) about 30.3 per cent, of the sea water in Little Egg Harbor at mean high water emptied into the Atlantic Ocean on the subsequent ebb tide. During mean summer-spring high tides (2.1 feet at tide gauge) 36.8 per cent, and during maximum summer-spring high tides (3.2 feet at tide gauge) 46.8 per cent was exchanged.

SALINITY. The first phase of this study involved daily collection of water samples from the "Cynthia" in Ezras Creek (1948) and in Thompson Creek (1949–1951) at the surface and just off the bottom at low and high slack water; it provided salinity reference curves (Fig. 15: 1948–1951) to which salinities in Lower Little Egg Harbor were related. The second, likewise undertaken over the four-summer period, involved sampling water in Lower Little Egg Harbor (a) at several vertical levels at different stages of the tidal cycle at a number of stationary stations; (b) following and sampling moving masses of water at several vertical levels from one slack period to the next; and (c) sampling horizontal transects over various portions of the bay as rapidly as possible within short portions of a single tidal cycle. Salinity samples were also taken simultaneously with most plankton samples. At the "Cynthia" surface water samples were dipped directly from the creek. Bottom samples were taken in a glass bottle perforated at the base and fastened to the end of a long glass tube; the flow of sea water into and out of the bottle was controlled by opening and closing of the upper tube. This simple device (first described to me by T. C. Nelson) permitted rapid collection of water samples immediately over the bottom. Away from the "Cynthia" subsurface water samples were pumped through a hose suspended at desired levels. Salinity was determined in the laboratory by means of Harvey's modified silver nitrate titration, with an accuracy of ±0.05 ^{0}/oo.

Salinity of sea water collected in the creeks from the "Cynthia," plotted as separate curves for bottom and surface, at both high and low water, is correlated with rainfall and tidal height in Figure 15. Close approximation of curves for bottom and surface flood slack water indicates thorough mixing of flood water entering these creeks. Salinities of sea water collected concurrently at Station 4 in Little Egg Harbor (Fig. 18) at all stages of the tides from surface to bottom coincided closely with those of both flood slack surface and flood slack bottom at Stations 1 and 2 and permitted use of the flood slack salinity data of the creeks as a guide to the level of salinities in Lower Little Egg Harbor.

Heavy precipitation in June and August, 1948, and June, 1951 (Fig. 15) depressed salinities slightly throughout Little Egg Harbor and steeply in the creeks. Ezras Creek is a tidal stream receiving no drainage from the land and thus the degree of dilution of sea water in it was related to the quantity of rainfall immediately over it and surrounding salt marsh (Fig. 15: 1948). Thompson Creek, on the other hand, receives fresh water from a small watershed 0.9 square mile in area, and lowering of salinity in it resulted from both direct rainfall and stream flow (Fig. 15: 1949–1951). Occasionally rainfall from small thunderstorms over the Thompson Creek watershed depressed salinities in the creek but was so localized that it was not registered on any of the existing rain gauges of the area (see especially August 10, 1950, Fig. 15). Fresh water ebbing from these creeks soon mixed with sea water in Little Egg Harbor, as demonstrated by the much higher salinities and virtual lack of stratification in the creeks during the late flood tide. From time to time spring high tides in the creeks were accompanied by higher salinities than normal (see especially the record high tide of July 8, 1948, Fig. 15); if not for the diluting effect of precipitation, increases in salinity would be detectible during all spring high tides because of the movement of bay water farther into the salt marshes.

One of the striking hydrographic features of Little Egg Harbor was the combined vertical and horizontal uniformity of salinity in the summer. During the four-summer period of these studies the maximum range in the vicinity of Station 4, inclusive of all stages of the tide and all vertical levels from surface to bottom, was only 8.8 ^{0}/oo (24.4 to 33.2 ^{0}/oo), while in Ezras and Thompson creeks it was 32 ^{0}/oo (see histograms, Fig. 18). This homogeneity may be explained by the fact that a proportionately small volume of fresh water enters the bay and is rapidly mixed by complex tidal currents moving over a broad, shallow basin and

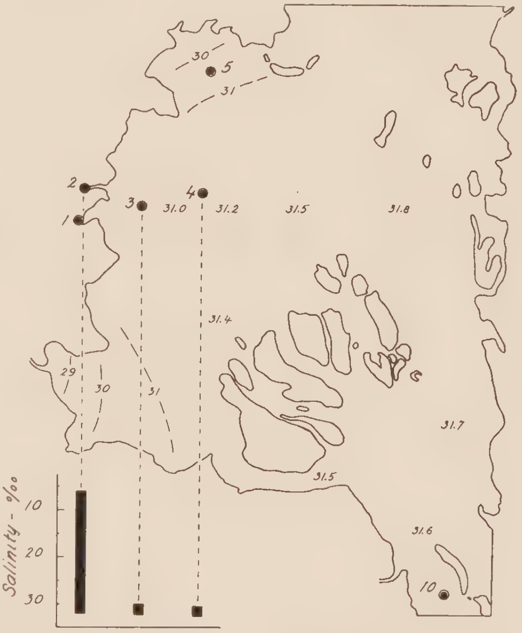


FIG. 18. Distribution of salinity in Little Egg Harbor. Isohalines represent average salinity in the vertical column of water at approximately mid tide when salinity in the vicinity of Station 4 was equivalent to 31.0 o/oo. Histograms at lower left depict range of salinity in the vertical column at ebb and flood slack over the four summers of 1948–1951 at Stations 2, 3, and 4.

by strong prevailing southwest winds. Figure 19 depicts vertical distribution of salinity from low to high water at three representative widely separated locations along the main axis of Lower Little Egg Harbor. At only one stratum, one-hour flood at Station 5, did the vertical range of salinity exceed 0.5 $^{o}/oo$. Greatest vertical mixing took place at maximum flow of the current at mid flood and mid ebb. Slightly higher salinities entered Stations 10 and 4 from down-bay during the late flood, whereas at Station 5 salinities dropped slightly during the flooding tide as a mass of water from the Edge Cove area, slightly diluted by Thompson Creek water, moved toward Parker Cove (Fig. 14). Horizontal distribution of salinity in the bay is plotted in Figure 18. Isohalines represent average salinities in the vertical column at approximately mid-tide when salinity in the vicinity of Station 4 (the principal larval sampling station in the bay) was equivalent to 31.0 $^{o}/oo$. This level of salinity, ± 1 $^{o}/oo$, prevailed during July, 1948, most of the summer of 1949, all of the summer of 1950, and July and August, 1951 (Fig. 15). Slightly lower salinities occurred in the Parker Cove and Tuckerton Cove areas, depressed by fresh-water flow from West Creek and Tuckerton Creek respectively. A small, increasing gradient of salinity was present across Lower Little Egg Harbor, and a decreasing gradient, down the channel from Tuckerton Cove and down the eastern channel toward the inlet from Beach Haven. These isohalines indicate slight dilution of sea water along the southwestern shore of Lower Little Egg Harbor, the concentrating effect of evaporation in extensive shallow areas in Upper Little Egg Harbor, and very slight dilution by mixing with brackish water in Great Bay to the south in and off Little Egg Inlet. The last observation is corroborated by the fact that salinity did not rise appreciably in Little Egg Harbor during dry summer months when evaporation exceeded inflow of fresh water from the Little Egg Harbor watershed (Table V), fresh water being contributed by the Mullica River via Great Bay and mixing in the joint Little Egg Inlet. As precipitation increased over the Little Egg Harbor area, with consequent acceleration of flushing, salinities in the western portion of the bay dropped, and the gradient of salinity across the bay steepened. When the maximum net monthly rate of fresh water was added to Little Egg Harbor (August, 1948, Table V), contributing the equivalent of 0.04 per cent of the mean high-tide volume of the bay per tidal cycle, salinities at Station 3 dropped to about 25 $^{o}/oo$. At the other extreme, during periods of minimal precipitation, fresh water was lost from Little Egg Harbor at the rate of 0.01 per cent of the mean high-tide volume of the bay per tidal cycle (August 1951, Table 5), elevating salinities at Station 3 to approximately 31 $^{o}/oo$.

It was not possible to determine net nontidal movements up-bay on the bottom and down-bay on the surface resulting from the flow of fresh water out of the bay, but vertical homogeneity of salinity throughout most of the bay during periods of minimal to moderate summer precipitation suggest that negligible nontidal movements existed then.

Temperature. The investigation of thermal properties of sea water in Little Egg Harbor was patterned after the investigation of salinity. In Ezras and Thompson creeks temperature of surface and bottom water was taken almost daily at ebb and flood slack water with a reversing thermometer. In addition a thermograph was installed on the tide gauge platform near the "Cynthia," and the mercury bulb was placed about a foot off the bottom in water approximately 4.5 feet deep at mean low water. In Little Egg Harbor temperatures were taken with a reversing thermometer as salinity and larval samples were collected.

Thermograph records for bottom water in the creeks for the four summers revealed the occurrence of thermal maximum in the late afternoon on sunny days; the thermal minima was in the early morning. These daily extremes, plotted in Figure 15, show a maximum range over the four summers of from 18.6° to 32.0°C., whereas the range recorded in the bay at Station 4 was from 18.6° to 28.6°C. Highest water temperatures in the creeks occurred when late ebbing tides coincided with hot, sunny afternoons. Because of the considerable distance of creek water from the inlet, about six statute miles across shallow Lower Little Egg Harbor, its thermal characteristics were most strongly influenced by insolation, and only slightly, if at all, by cooler flood water from the ocean.

Daily surface and bottom water temperatures (not plotted) taken at ebb and flood slack off the "Cynthia" revealed a maximal vertical thermal difference between surface and bottom over the four summers of 4.0°C. at ebb and 2.5°C. at flood slack. However, such extremes were uncommon. On the whole, vertical thermal mixing of creek water was thorough. For example, in 1951 (the year representative of the four summers) in only 5 of the 109 sets of

Table VIII

Tidal, salinity, temperature, and current velocity data collected during study of movements of water masses in Lower Little Egg Harbor as plotted in Figure 16.

Date of run	Difference in tide level between low and high tide at tide guage, feet	Duration of observation, hours	Range in surface salinity during observations, and maximum difference, o/oo	Range in surface and bottom temperatures during observations, and maximum difference, °C.	Maximum current velocity observed during run, feet/sec.
8–27–51	low to high: 1.65	7.0	31.22 to 31.29: 0.07	21.8 to 22.7: 0.9	2.16
9– 1–50	low to mid flood: 1.80	3.6	—	24.6 to 25.0: 0.4	1.21
8–23–51	low to high: 1.95	6.3	31.09 to 31.33: 0.24	23.7 to 24.7: 1.0	0.92
7–14–50	high to low: 1.20	6.2	31.27 to 31.41: 0.14	25.6 to 26.1: 0.5	0.20
8–13–51	high to low: 1.40	6.7	30.40 to 30.80: 0.40	26.3 to 26.9: 0.6	0.33
8–22–51	low to high: 1.95	6.5	30.82 to 31.76: 0.06	25.4 to 25.6: 0.2	0.36
8–29–50	low to high: 1.80	6.5	—	25.8 to 27.4: 1.6	0.92

ebb and flood-slack surface and bottom temperature readings recorded during the summer were differences between surface and bottom 1.4°C. or greater. In 30 of these sets no measurable vertical difference could be detected; 7 of these occurred at ebb slack and 23 at flood slack. These data support those on salinity, which demonstrate that vertical mixing of water in the creeks was most thorough during the late flood tide.

Vertical thermal stratification in Lower Little Egg Harbar during the four summers was negligible at all stages of tide (Fig. 21), and temperature of separate water masses followed in the bay from mid morning to late afternoon did not vary more than 1.6°C. (Table VIII, Fig. 16). Mean daily water temperatures for Station 4, superimposed on daily maximum-minimum temperatures of creek water recorded by the thermograph (Fig. 15), occupy an approximate mean position on curves from creek-water temperatures. Thermograph recordings thus provided a useful guide to water temperatures in the central basin of Lower Little Egg Harbor.

In Lower Little Egg Harbor an increasing thermal gradient radiated from the inlet toward Edge Cove and Upper Little Egg Harbor. This gradient was most pronounced during late flood tides of periods of maximal water tem-

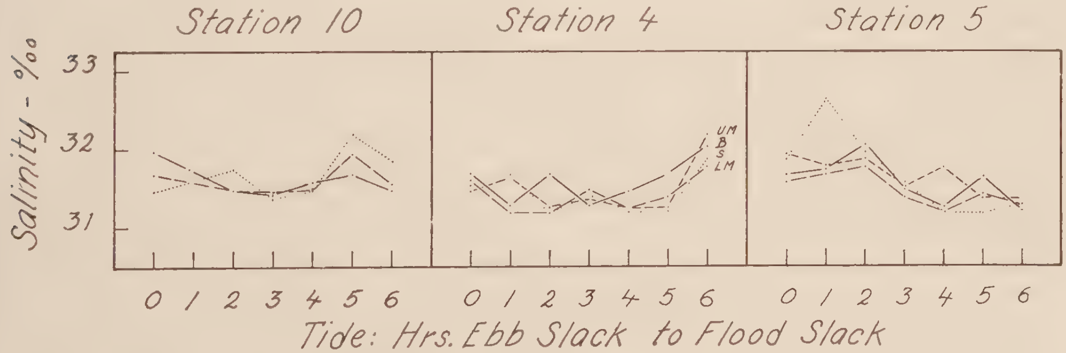


FIG. 19. Vertical distribution of salinity at Station 10 (inlet), August 8, in water 29.5 feet deep at low water; at Station 4, July 21, 8 feet deep; and at Station 5 (Parker Cove), July 25, 1950, 5 feet deep. S, surface; UM, upper middle stratum; LM, lower middle stratum; B, bottom salinity.

peratures in the Edge Cove area (Fig. 20). As the tide flooded, cool inlet water moved principally up the main channel of the bay, pushing the warmer water before it. On the ebb the one-degree isotherms spread as they moved down the bay toward the inlet. As insolation heat decreased, temperatures at the head of the bay and in the inlet approached each other. Data on horizontal distribution of water temperature complement those on movement of water masses in the bay (Figs. 16, 17) and demonstrate that for the most part cool inlet water flowed unidirectionally up and down the main channels, mixing only peripherally with that in the central basin of Lower Little Egg Harbor.

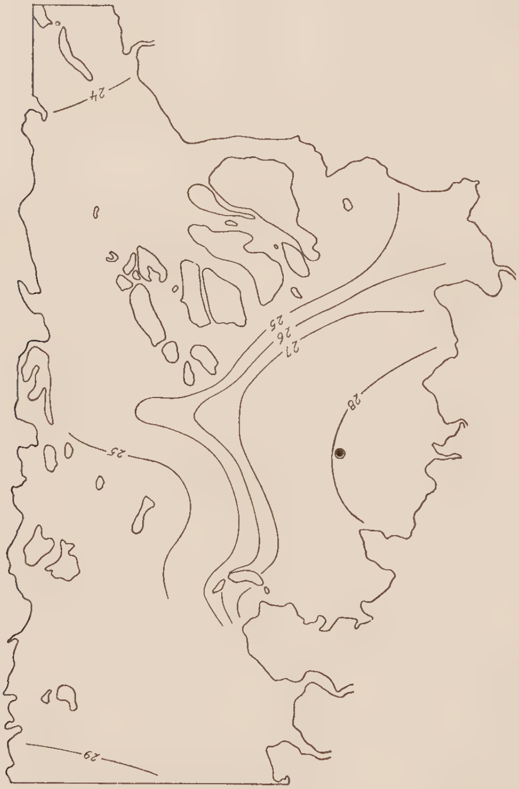


FIG. 20. Water temperatures, °C, in Little Egg Harbor during late flood tide on July 4, 1949, when tide level at flood slack registered 1.85 feet on the tide gauge. Maximum high tide that summer registered 2.82 feet (Table VI). Isotherms represent mean vertical temperatures.

The thoroughness of vertical thermal mixing is illustrated in Figure 21 (compare with Figs. 14, 20). Representative stations 10, 7, 4, and 5 along the long axis of the estuary were sampled vertically at bottom, middle, and surface at hourly intervals from ebb slack to flood slack. On warm, sunny days the entire vertical column of water warmed slightly during the course of the day, even during the flooding tide. This is especially striking at Station 7 (compare with Fig. 15, for June 29, 1948), where observations were made on a hot day preceded by several cool ones.

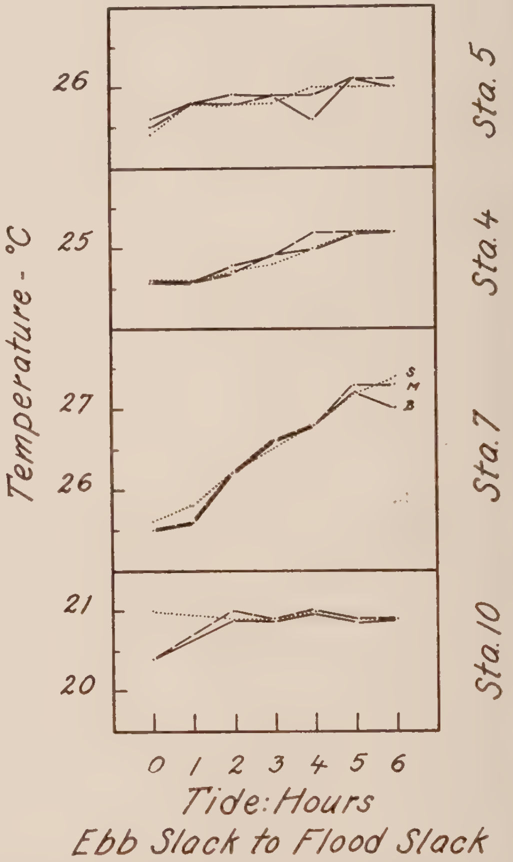


FIG. 21. Vertical distribution of temperature at Station 10 (inlet), Aug. 8, 1950, in water 29.5 feet deep at low water; at Station 7, June 29, 1948, 6 feet deep; at Station 4, July 21, 1950, 8 feet deep; and at Station 5 (Parker Cove), July 25, 1950, 5 feet deep, at approximately hourly intervals from ebb slack to flood slack. S, surface; M, middle; B, bottom temperature.

SEDIMENTS AND TRANSPARENCY OF WATER. Sediments in the central basin of Lower Little Egg Harbor consisted of firmly compacted fine sand and silt with a small percentage of organic detritus. Detrital content increased markedly in the direction of the salt marshes, bottoms becoming quite soft along the landward area of the bay. Sediments in channels and intertidal flats surrounding the marsh islands in the southern part of the bay consisted of coarser clean sand. Bivalve shell fragments, mostly of *Crassostrea virginica* and *Mercenaria mercenaria,* were distributed irregularly over the bottom of the bay, most densely in areas along the northwestern section, where oysters were being cultivated. Except for scattered shell deposits, salt-marsh creek bottoms were composed of a firm central and soft marginal zones of fine, black, highly reducing organic mud.

Transparency was measured with a Secchi disk. During periods of calm to light wind, over the cycle of the tide, the disk disappeared from view at depths ranging from 0.6 to 1.2 meters (approximately 2 to 4 feet) at Stations 1 and 2 in the creeks, and from 1.2 to 1.8 meters (approximately 4 to 6 feet) at Station 4 in the central basin of Lower Little Egg Harbor. Transparency decreased as tidal flow increased in the tidal cycle. Bay waters, which received relatively little cedar swamp discharge, were noticeably free of stains. Generally clear water in the bay greatly facilitated collection, sorting, and study of plankton samples.

SUMMARY OF HYDROGRAPHY OF LITTLE EGG HARBOR. Float and current studies disclosed that in the central basin of Lower Little Egg Harbor tidal excursion was relatively short as compared with that on the eastern side. Computations of net movement of fresh water into the bay during the summer indicated that insignificant flushing of bay water into the ocean fluctuated with the net flow of sea water into the bay during periods when evaporation rate exceeded the rate of fresh-water inflow. The movement of relatively small volumes of fresh water into the bay from all sources combined with a complex circulation pattern and wind action, produced relatively uniform high summer salinities throughout the bay and almost eliminated vertical salinity and thermal stratification. The uniformity of salinity suggests rapid and complete mixing of the water. Calculation of the volume of water in the bay at various stages of the tide showed that exchange was substantial. Thus the central basin of Lower Little Egg Harbor functioned somewhat as a retaining vessel of relatively homogeneous sea water in which a large proportion of clam larvae in many instances were held for at least the duration of the veliger stage.

2. Behavior and Autecology of Veligers in Little Egg Harbor

Our field study of veligers of *M. mercenaria* was designed to provide information on natality rate; quantitative seasonal, horizontal, and vertical distribution; and density, duration, movements, and mortality rate of the pelagic stages of the larvae in relation to several environmental variables: horizontal movements of water masses, current velocity and direction in various vertical strata, exchange, flushing, stage of the tide, horizontal and vertical distribution of temperature and salinity, light intensity and time of day, relative velocity and direction of the wind, general nature of the bottom, and density and distribution of parent *M. mercenaria* in the bottom.

DISTRIBUTION AND ABUNDANCE OF ADULT CLAMS. Before 1920 Little Egg Harbor communicated with the Atlantic Ocean by way of Little Egg Inlet through a narrow channel. Salinity in Little Egg Harbor was low, and bottoms were dominated by the oyster *Crassostrea virginica.* On February 5–6, 1920, a heavy storm cut a large, shallow additional inlet, Beach Haven Inlet, just north of the old one, thereby permanently accelerating exchange and elevation of salinity in the bay. Oyster production began a steady decline correlated with higher salinities and increasing quantities of sand which accumulated over the bottom (T. C. Nelson, personal communication). After this invasion of saltier water *M. mercenaria* became the dominant bottom organism in the sound and thereafter provided a livelihood for a considerable proportion of the local human population of Tuckerton and vicinity.

During the summers of 1948–1951 *M. mercenaria* were found in varying though dense concentrations in all bottoms of Lower Little Egg Harbor. Densest populations occurred in the open lower portion of the central basin of the bay immediately northwest of the marsh islands above the inlet (Fig. 14). The largest clams were found in tidal creeks and salt marsh ponds, though present in significantly less numbers. In the bay, clams were generally smaller in size and the condition of the flesh was not so good as that of those in the creeks. Continuous commercial tonging (power dredging was prohibited by state law) in the bay year after year probably reduced the maximum size of clams there. No explanation is available for the inferior meat of clams in the open bay, though Pomeroy (personal communication) has suggested an insufficient food supply to support such large populations. The relation of primary production to production of clams in this bay is worth studying, particularly in view of the interesting hydrography and large populations of clams sustained there.

Data are available which show that Lower Little Egg Harbor has supported a high annual yield of *M. mercenaria* since at least 1929 (Fig. 22). Mr. E. Walter Parsons, Jr., a planter and shipper of oysters and clams in the Tuckerton area, has kept an accurate record of marketable clams passing through his shipping plant from Lower Little Egg Harbor and has permitted us to publish these data. He estimates that during the period 1929–1951 his plant received about one-tenth of the clams harvested commercially in this bay; thus his figures provide a rough index of the total annual production of clams there. The minimum harvest received by Mr. Parsons was 4,565,000 clams in 1932 and the maximum was 16,726,000 clams in 1946. The minimal total yield of the bay (yield to all clammers based on Mr. Parson's estimate) in 1932 represents an average take of 0.8 clam per square yard of bay bottom, while the average take for the maximum yield in 1946 was 3 clams per square yard per year. Whether trends in the curve of clam production over this twenty-two-year period (Fig. 22) represent fluctuations in tonging effort, in clam populations, or both is not known.

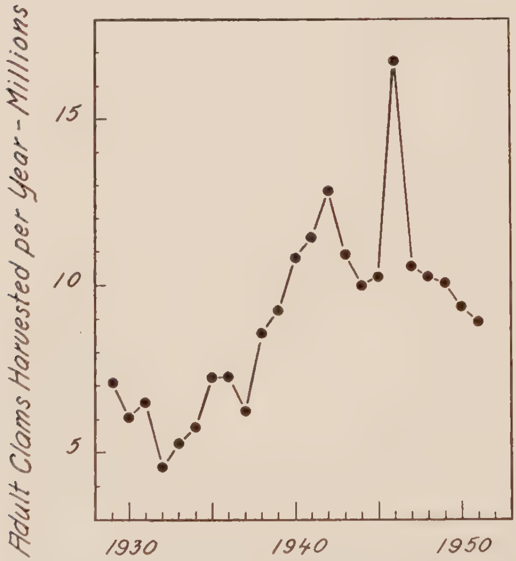


Fig. 22. Number of marketable *M. mercenaria* received per year by E. Walter Parsons' Shipping House, Tuckerton, New Jersey, from Lower Little Egg Harbor.

Abundant filter-feeding mollusks competing for food with *M. mercenaria* in Little Egg Harbor were: *Arca campechiensis, Crassostrea virginica, Anomia simplex, Pitar morrhuana, Modiolus demissus, Ensis directus, Mya arenaria, Tellina tenera, Gemma gemma, Crepidula fornicata,* and in the lower reaches of the bay *Spisula solidissima* and *Mytilus edulis.* The following principal predators of post-setting stages of *M. mercenaria* were found: *Callinectes sapidus,* Xanthidae, *Polinices duplicatus, P. heros, Urosalpinx cinerea, Eupleura caudata, Busycon canaliculatum,* and *B. carica.* Moon snails and knobbed conchs were more abundant in the lower extremities of the bay, channeled conchs in the upper regions; crabs and oyster drills were distributed more or less throughout the bay.

It is worth emphasizing that clam production in Lower Little Egg Harbor, in spite of inroads by man and nonhuman predators, remained at a high level over a long period of time, producing the dense swarms of larvae which made possible these autecological studies.

Methods of Collecting and Studying Clam Larvae. Plankton samples were pumped manually into a metal drum in the boat through a graduated intake hose five meters long by means of a large calibrated brass oscillating clock pump. The drum was outfitted with automatic siphons for draining. Sea water was poured into the drum through a standard conically shaped silk-bolting-cloth net suspended in sea water in the drum and equipped with a detachable screened bucket which permitted ready removal of plankton samples to bottles. The bulk of sampling was performed with 18 XXX silk-bolting cloth which retained the smallest shelled stages of clam larvae. For sampling older stages only 12 XXX silk-bolting-cloth nets were used. The intake of the hose was screwed into an opening in the center of a metal disk about six inches in diameter, opposed by a similar solid disk parallel to and held about an inch and a half from the first by a strip of one-eighth-inch mesh bronze screen soldered to the circumference of the two disks (Fig. 23). This basket excluded larger organisms from plankton samples and, more importantly, guided collection of larval samples from a relatively narrow vertical stratum of sea water. Lead weights secured to the intake basket steadied the hose in a vertical position in swiftly flowing water. A galvanized iron disk approximately eighteen inches in diameter with an upturned edge of about one-half inch was tied, when needed, under the intake basket of the hose to permit pumping plankton samples immediately off the bottom from an anchored

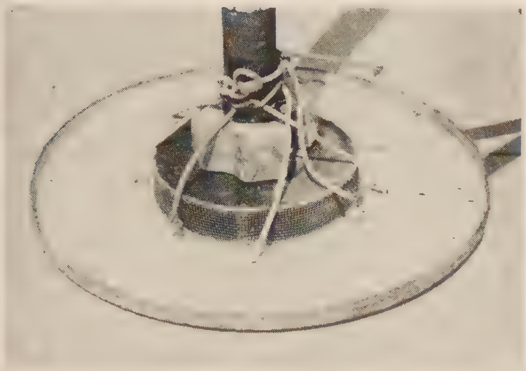


FIG. 23. Screened basket and bottom disk on intake of hose used in pumping plankton samples in Little Egg Harbor.

boat (Fig. 23). Samples were pumped after sediment thrown into suspension by the lowering of the gear had been removed by tidal currents. Single vertical samples were generally pumped while the boat floated over a station with the tide, whereas series of vertical samples were taken from the boat at anchor. The volume of plankton samples ranged from 25 liters when larvae were numerous to 1000 liters when ready-to-set larvae were scarce.

Routine sampling of larvae was carried out off the "Cynthia" at Stations 1 and 2 and in the bay at Stations 3 and 4 to provide a general picture of daily larval abundance. Horizontal distribution of larvae, obtained from transects over different portions of the bay, demonstrated that maximum concentrations of clam larvae occurred principally in the general area between Stations 4 and 8. This information, and the proximity of the point to the "Cynthia," provided the basis for location of our major sampling station at Station 4 (Fig. 14).

Series of vertical plankton samples from surface to bottom, in that order, during the cycle of the tide were taken mainly at Stations 4, 2, and 1. Each vertical plankton sample of the most complete vertical series was accompanied by observations on time of day, depth, current velocity and direction of current, temperature, and salinity; and the series as a whole was accompanied by stage of the tide, relative intensity of light striking the surface of the water, relative velocity and direction of the wind and thus degree of disturbance of the surface of the water, transparency of the water, nature of the bottom, and proximity to spawning parents.

With the apparatus described, and with fifty-liter samples at a time, two operators required approximately five minutes to complete observations at each stratum. Thus in any mass of water sampled serially in this manner, the horizontal spatial and temporal interval between the surface and bottom set of observations would depend upon the depth of water, the number of vertical samples taken, and the velocity of the current. This slanting of the vertical series should be kept in mind in the interpretation of data taken from them. In less complete vertical series, some of the observations accompanying the plankton sample were omitted. Ideally, simultaneous observations for all factors should have been made at all vertical strata, but this was not possible at the time of the study. To my knowledge this has not yet been achieved in estuarine planktonological studies and should be strived for in the future.

Plankton samples were flushed from the plankton net into stoppered glass bottles with a bulb pipette and killed and preserved by addition of neutralized formalin (full-strength formalin saturated with sodium borate) to make 2 per cent formalin in the plankton sample. This solution kills larvae quickly with soft parts retracted within the valves and does not bleach or alter the larval shell for several days. In samples containing much organic detritus, however, the *p*H of the preservative soon drops, bringing about erosion of the valves. Such "dirty" samples were usually examined first. Fluids for preservation of bivalve larvae for long periods of time have been described (Carriker, 1950). In the best of these, bivalve larvae free of organic detritus have retained glossy, clear valves and some pigment incorporated in the shells for about eight years. This fluid has the following composition, with a *p*H of 8:

Commercial formalin	5 cc.
Cane sugar	50 g.
$Na_2B_40_7$ 10 H_2O, sodium tetraborate	0.25 g.
Filtered sea water, to make	500 cc.

Cleaning, sorting, identification, and counting of larvae of *M. mercenaria* were performed in the "Cynthia" laboratory as soon after sampling as possible. In formalin-treated practice plankton samples were washed with fresh water through a series of three nested stainless steel screens three inches in diameter with successive maximum diagonal pore dimensions of 340 μ (screen No. 60), 150 μ (No. 150), and 65 μ (No. 325). Clam larvae first appeared in the water as shelled veligers averaging about 95 μ in length and disappeared from the water at lengths ranging from 180 to 200 μ. Thus all clam larvae passed through screen No. 60 but larger plankters and gross materials were retained. The contents of this screen were examined microscopically directly on the screen. Most umboned clam larvae, approximately 140 μ and longer, were held on screen No. 150. This fraction of the plankton with accompanying detritus was rinsed into a deeply concave glass swirling dish (such as the bottom half of a macro Kjeldahl flask). Fractions relatively free of organic detritus were examined without washing. Larvae were sorted and counted in the dish under a magnification of 34X. If detritus (usually in the form of minute fecal pellets) was abundant, as in samples pumped near the bottom, mollusk larvae and sand were swirled gently to the center of the dish with a small stream of water from a bulb pipette; detritus remaining at the periphery of the dish after the water came to a standstill was drawn off gently with another bulb pipette. Occasionally, as a check on the possible loss of larvae in the cleaning process, washings were allowed to settle in a settling cone and sediment in this was re-examined for veligers. Material retained on the finest screen (No. 325) was rinsed through a funnel into a 50 ml. stoppered graduate and the volume of water therein brought to 50 ml. The graduate was then shaken thoroughly to disperse bivalve larvae uniformly, and duplicate 5 cc. aliquot portions, each taken immediately after shaking, were drawn quickly from the middle of the graduate and examined in a shallow, concave glass dish under a magnification of 34X. A dissecting needle with tip filed flat on opposing sides facilitated sorting and counting. A multiple laboratory counter accelerated recording of the counts. Larval densities were expressed as number of larvae per 100 liters of native sea water. Examination of size fractions of the plankton samples in this manner has the advantage of making possible maximum accuracy of sorting and counting of the older, least numerous stages of clam larvae.

In all, during the four summers of 1948–1951, some 1,100 plankton samples were collected and examined.

Accurate identification of all stages of clam larvae in plankton samples was the most difficult aspect of our study in Little Egg Harbor. The close, sometimes bewildering similarity of a few of the developmental stages of some unknown species of bivalves to comparable stages of *M. mercenaria* in the bay forced us during the summers of 1947 and 1948 to undertake a preliminary systematic survey of the different species of bivalve larvae in the area (Carriker, 1950). This was done on the premise that recognition of the majority of these (if not to actual species at least to type) would minimize confusion of different stages of clam larvae with those of other closely related species. To this end all the different available kinds of bivalve larvae in the plankton were catalogued: in ten species, identification was possible by reference to the scanty literature; in eleven other species in hand identification was not possible, and provisional names were applied. Representative stages of the different species were measured, sketched, and preserved, and main diagnostic features were recorded. On the basis of these preliminary data, we constructed an incomplete taxonomic key to the bivalve larval types in the bay. Reference to this key, to preserved bivalve larval types, and to clam larvae cultures in our laboratory early in the summer of 1948 from gametes of known parents made possible positive identification of the larvae *M. mercenaria* in the plankton after July 14, 1948.

TEMPORAL DISTRIBUTION OF CLAM LARVAE. Loosanoff (1954) has demonstrated that specimens of *M. mercenaria* in the laboratory are able to develop normal gonads and to spawn repeatedly at approximately six-month intervals independently of day length, tidal rhythm, precipitation, kinds of plankton, and other factors present in the late spring and early summer when gametogenesis occurs normally. Spawning is induced in the laboratory, at least, by thermal and chemical stimuli. Although the factors that stimulate spawning under natural conditions are still obscure, it appears that in Little Egg Harbor spawning was triggered at least in part by thermal stimulation.

Seasonal distribution of clam larvae, associated with spawning time of swarms, daily median water temperature, and daily mean high-tide level is given in Figures 24 through 27. High-tide level is based on a mean low-water level of zero, and will be referred to hereafter as tidal amplitude. Other associated data on precipitation, salinity, maximum-minimum water temperatures, and daily low- and high-tide levels are presented in Figure 15.

Each summer the largest, most dense swarms of clam larvae appeared during the month of July: July 28–29, 1948; July 5, 1949; July 5–6, 1950; July 9–12, 21–22, 1951. The number of spawnings varied considerably from

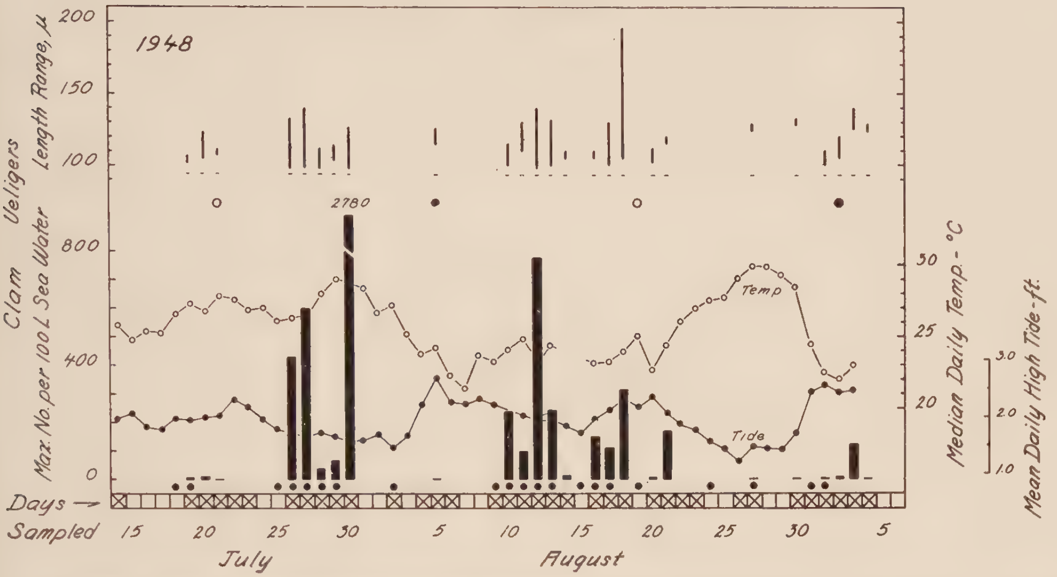


FIG. 24. Seasonal distribution, abundance, and range of length of veligers of *M. mercenaria* in upper Lower Little Egg Harbor (Stations 1–4) in the summer of 1948. Larval densities represent maximum number of larvae of all sizes per 100 liters of sea water at any of the vertical strata sampled per day; densities greater than 800 per 100 liter are expressed numerically at the top of the broken bar in the histogram. The date of spawning of each swarm of larvae (approximately one day prior to first appearance of earliest straight-hinged veligers) is indicated by solid circles under the histogram. Curves for median daily water temperatures (from thermograph recordings) and for height of mean daily high tide (from tide gauge recordings) are plotted near bottom of figure. See Figure 15: 1948, for additional environmental information. Length ranges (maximum and minimum lengths of larvae in a representative aliquot portion of each plankton sample) suggest, where there are sufficient data, the rate of growth (dotted diagonal lines) of individuals in each swarm based on the more complete data of the single isolated swarm of June 24–July 1, 1950 (Figs. 26, 31). The broken base line under length ranges represents length of shortest larvae found in plankton, 93 μ. Frequency of sampling is indicated by the crossed squares at the bottom of the figure.

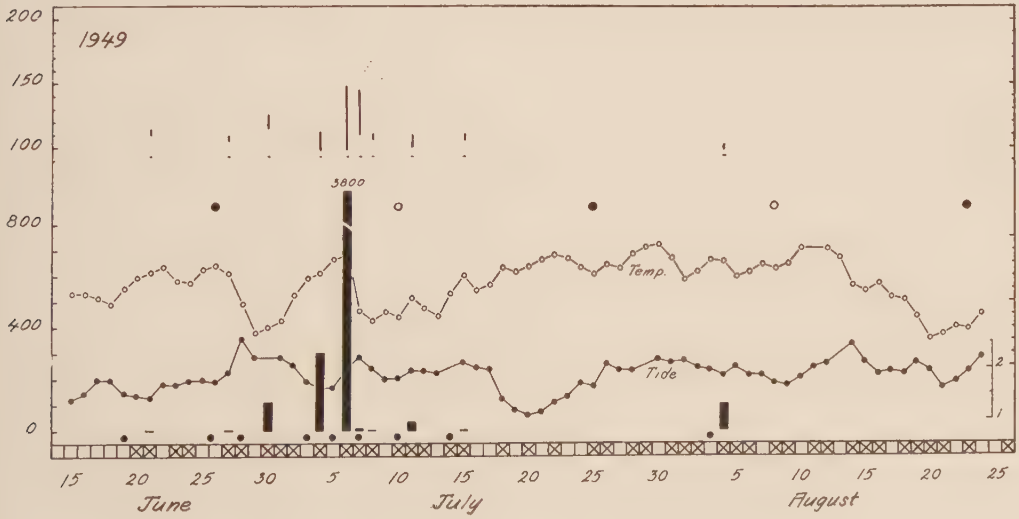


FIG. 25. Seasonal distribution, abundance, and range of length of veligers of *M. mercenaria* in upper Lower Little Egg Harbor (Stations 2–4) in the summer of 1949. Remainder of legend as in Figure 24. See Figure 15: 1949, for other environmental information.

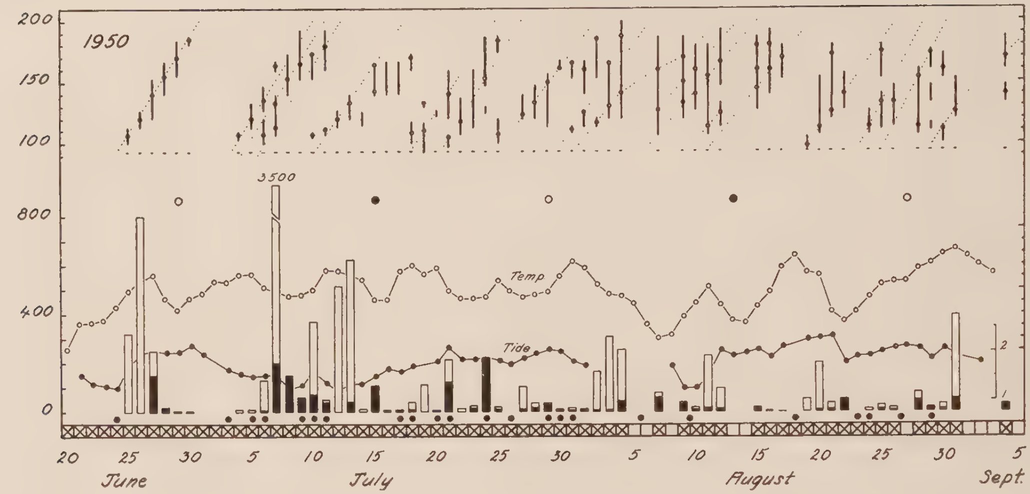


FIG. 26. Seasonal distribution, abundance, and range of length of veligers of *M. mercenaria* in upper Lower Little Egg Harbor (Stations 2–4) in the summer of 1950. Each open circle joined by dotted diagonal lines at the top of the figure represents the length of the most abundant size group(s) in the sample. Open histograms represent clam larvae ranging in length from 93 to 140 μ; solid histograms, represent 141 μ to setting stage. Remainder of legend as in Figure 24. See Figure 15: 1950, for other environmental information.

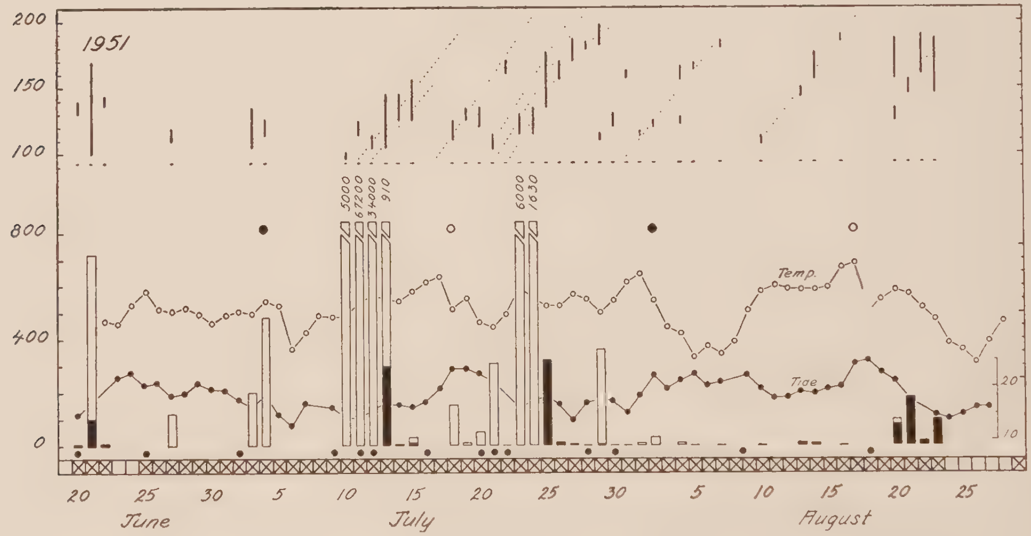


FIG. 27. Seasonal distribution, abundance, and range of length of veligers of *M. mercenaria* in upper Lower Little Egg Harbor (Stations 2–4) in the summer of 1951. Remainder of legend as in Figures 24 and 26. See Figure 15: 1951, for other environmental information.

summer to summer, decreasing in the following order: 1950, 1948, 1951, 1949. The fewest larvae were found during the summer of 1949, and maximum densities in 1951. Landers (1954) likewise found differences in the time of occurrence and duration of spawning of *M. mercenaria* in Narragansett Bay, Rhode Island. He suggests that variations in spawning patterns within and between seasons may be caused by variations in water temperature, early higher-than-average temperatures concentrating and advancing the spawning period and consistently low seasonal temperatures retarding and prolonging spawning at a high level. In a general way, Landers' hypothesis applies in part to the two summers in Little Egg Harbor in which minimal and maximal spawning was observed. The prolonged high-intensity spawning in the summer of 1950 (Fig. 26) was accompanied by low temperatures in early June and moderate temperatures throughout the rest of the summer. By contrast, what little spawning was observed in 1949 (Fig. 25) was concentrated in the early part of the summer during a period of moderate water temperatures, and thereafter, when almost no spawning occurred, water temperatures remained high. Abundance and frequency of spawning is probably not explained on the basis of temperature alone, but temperature probably is one factor.

Of the six major spawnings which occurred in Little Egg Harbor during the four summers followed by maximum densities of over 1,000 larvae per 100 liters of sea water, five (July 29, 1948; July 5, 1949; July 5, 1950; and July 9 and 11, 1951) took place in a period of two or more days of rising median daily water temperatures; and one (July 21, 1951) coincided with falling median daily water temperatures (Figs. 24–27). Analysis of all spawnings over the four-summer period (Fig. 28) indicates that 73 per cent of a total of sixty-seven spawnings occurred on rising median daily water temperatures and twenty-seven per cent of falling temperatures. The average median daily temperature for spawnings which took place on rising temperatures was 26.2°C.; for spawnings on falling median daily temperatures, the average was 24.4°C., giving an over-all average median daily spawning temperature of 25.7°C. These observations support those in the laboratory, where we obtained both artificial and spontaneous spawnings on both rising and falling temperatures. Seventy-two per cent of the spawnings (Fig. 28) took place within six-degree days (sum of number of degrees of change per day) following a peak or trough in the curve for median daily water temperature, suggesting that only slight changes in temperature stimulate spawning after gonads are physiologically mature and the animal is ready to discharge gametes. The density of larval swarms bore no apparent relationship to the number of degree days between the time of spawning and the previous median daily thermal change (Fig. 28).

Median daily spawning temperatures encountered for swarms of all densities during the four summers were approximately the same, 25.7°C. (Fig. 29b). Spawnings occurred

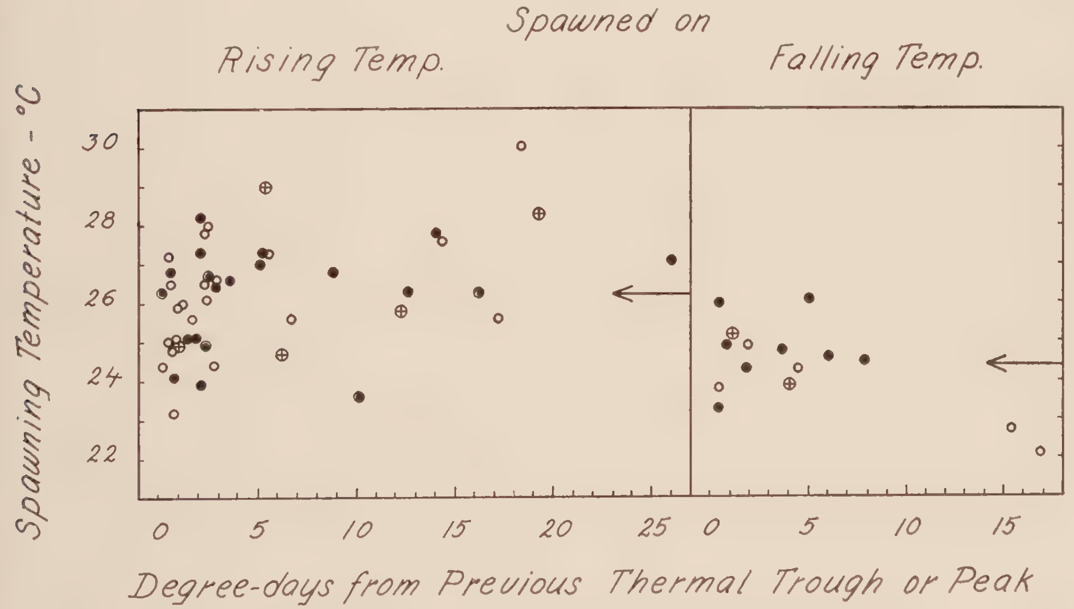


FIG. 28. Comparison of spawning of *M. mercenaria* in Little Egg Harbor on rising and on falling median daily water temperatures (compare with data in Figures 24–27) during summers of 1948–1951. Median daily water temperature at which spawning occurred is plotted against number of degree-days intervening between the previous trough in the thermal curve and the spawning temperature (for spawnings occurring on rising temperatures) and between the previous peak and spawning temperature (or spawnings occurring on falling temperatures). Maximum daily density of larval populations is expressed as follows: ○, 1–100; ●, 101–500; ⊙, 501–1000; and ⊕, 1001–67,000 early straight-hinged larvae per 100 liters. Degree-days refer to total number of degrees rise or fall per day in the curve for median daily temperature from the previous trough or peak to spawning.

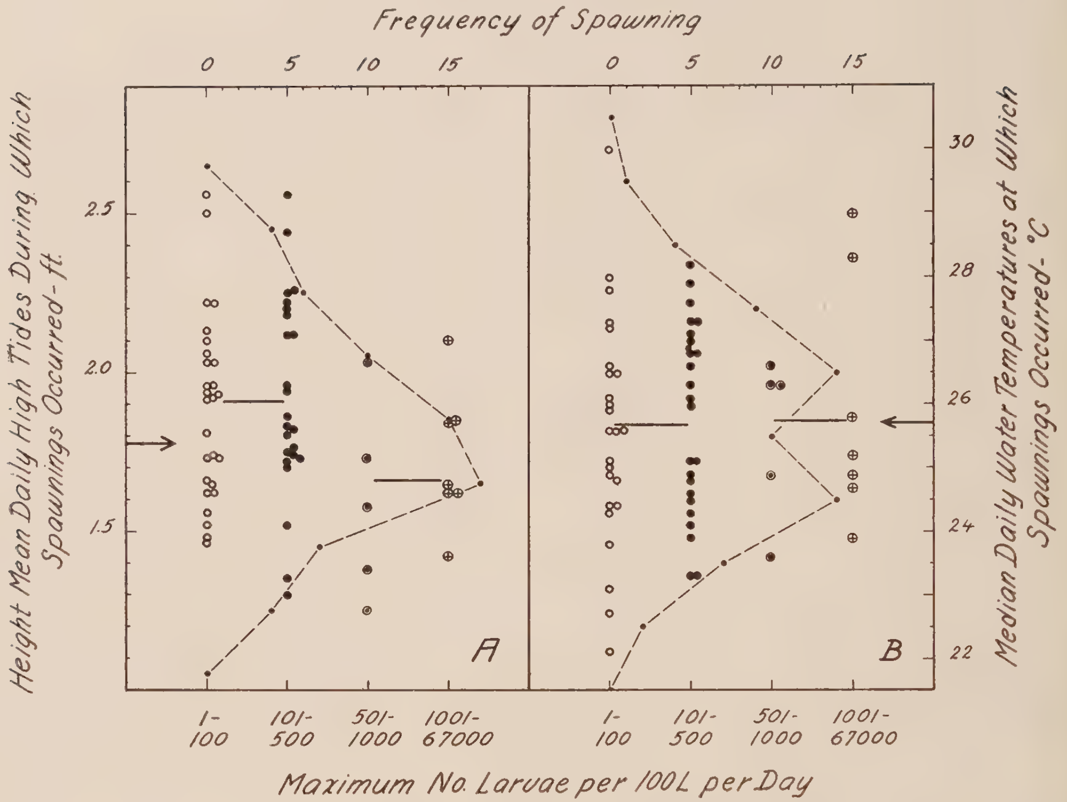


FIG. 29. Relation of spawning of swarms of larvae of *M. mercenaria* of different densities in Little Egg Harbor during summers of 1948–1951 to (A) height of mean daily high tides (roughly tidal amplitude) and (B) median daily water temperatures. See legend of Figure 28 for symbols of larval densities. Arrow extending from the y-axis in A designates the mean level of high tides at which all spawnings occurred (1.78 feet), tide levels throughout equated to 0 feet mean low water; bars in A indicate mean level of high tides at which spawnings of low-density swarms (1.91 feet) and high-density swarms (1.66 feet) occurred. Arrow extending from y-axis in B designates mean daily spawning temperature for all swarms (25.7°C), and the bars facing the arrow indicate mean daily spawning temperatures for the low- and high-density larval swarms. Mean minimum median summer water temperature for the four summers was 21.2°C, and mean maximum median summer water temperature was 29.1°C. Broken-line curves associate frequency of spawning and tidal amplitude (at 0.2 ft. intervals) in A, and temperature (1° intervals) in B.

over a median daily range of water temperatures of 22° to 30°C. but maximum frequency of spawning occurred within the thermal range of 24°–26°C. (Fig. 29b).

As suggested in Figures 24 through 27 and amplified in Figure 30, spawnings occurred more frequently and more high-density swarms of early-stage clam larvae appeared in the water during neap than during spring-tide periods. Mean amplitude of the four summer maximum tides was 2.88 feet, and mean amplitude of all tides of the four summers was 1.85 feet, based on a level at mean low water of zero. Mean amplitude of all tides during which spawnings occurred was 1.78 feet, and within a range of amplitudes of 1.25 to 2.56 feet (Fig. 29a). Low-density swarms were spawned at a mean tidal amplitude of 1.91 feet and high-density swarms at 1.66 feet. The frequency of spawning was maximal within a range of tidal amplitudes of 1.6 to 1.9 feet (Fig. 29a). Thus the total number of spawnings per day, as well as the density of swarms, increased from spring to neap tides, paralleling an increase in frequency of spawning with successive decreases of tidal amplitude to 1.6 feet.

Curves for median daily water temperature and mean daily tidal amplitude in Figures 24 through 27 frequently diverge and converge in a roughly symmetrical pattern. This correspondence suggests that during low tides of neap periods, when minimal exchange occurred with the cooler ocean water, bay water temperatures rose above those of spring-tide periods. However, because of the distance of Station 4 from the inlet and general isolation of the mass of water at Station 4 (Fig. 16, 17, 20) from the inlet, the partial correspondence of these curves was coincidental. Study of the relationship of air temperature, water temperature, and tidal amplitude at Station 4 over periods of several summer months demonstrated a correlation between only air and water temperatures.

The cooling effect of ocean water was demonstrable in the lower portions of the central basin of Lower Little Egg Harbor (Fig. 20), but only during the late flood of high spring tides. Since maximum density of parents was met in the southern region of the central basin within the influence of cooling high spring tidal water, and maximum density of swarms of early veligers at Station 4 predominated during neap tides, it is probable that the higher water temperatures of neap tides triggered the spawning of these swarms (Fig. 30). The bulk of spawning probably took place at or close to the ebb slack period when maximal water temperatures prevailed, since larvae appeared in greatest number at Station 4 during late flood and early ebb tide, carried there by tidal transport from the area of maximum parental densities in the lower part of the central basin (Figs. 16, 17). Other factors than heat, such as kind and quantity of food (Thorson 1950), may possibly have contributed to spawning and should not be entirely discounted. Spawning at or just after low tide would be advantageous to the larvae, since they would be transported up-bay from the spawning area rather than down-bay toward the inlet, with possible loss to sea.

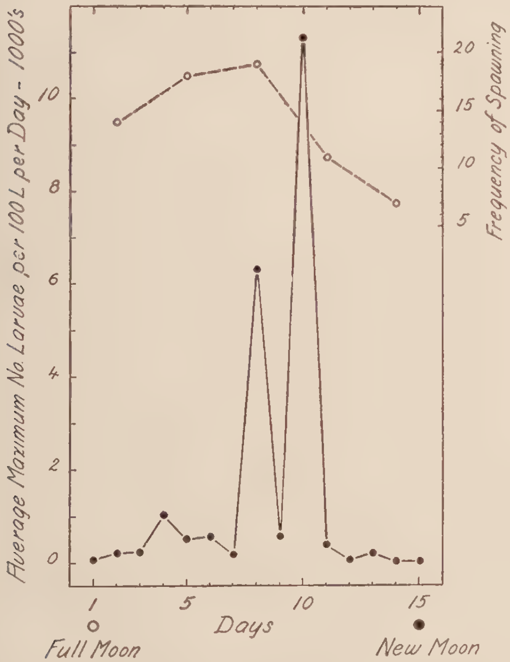


FIG. 30. Relation of frequency of spawning of *M. mercenaria* (3-day means; total of 67 spawnings in 4 summers) and spawning time, and relation of density of resulting larval swarms to full and new moon. All data are equated to a 15-day interval between full and new moon.

Landers (1954) reports that hard clams in intertidal areas in Narragansett Bay spawned earlier in the season than those in deeper water even though the prevailing temperature of the water mass over both was the same. In this ecological situation, warming of the exposed bottoms triggered release of gametes in the same manner as the higher water temperatures of neap-tide periods in Little Egg Harbor.

Data presented in Figures 24 through 27 permit approximation of the percentage of survival of clam larvae during planktonic existence. In Table IX are tabulated pertinent data on the ten densest swarms encountered during the four summers. In six of these swarms (marked by an asterisk), late umboned veliger and pediveliger larvae were found in the water toward the termination of planktonic existence. Approximate densities of early and late stages suggest a survival value (which probably also reflects an unknown degree of dispersion of the larvae) of roughly 2.6 per cent. These six swarms coincided with periods of little or no rainfall and medium to low tidal amplitudes (Fig. 15).

The four other swarms listed in Table IX (spawned on July 28–29, 1948; July 5, 1949; and July 11–12, 1951), however, completely disappeared from the water at Station 4 at an early age.

Loss of these larval swarms may be partially explained by flushing during periods of heavy rainfall and by high spring tidal exchanges, since in all four cases cited above larvae disappeared coincident with mean daily tidal amplitudes in excess of 2.1 feet (tidal exchanges exceeding 37 per cent) and rainfall ranging from 1.21 to 3.96 inches. This loss may be elucidated for the swarm of July 28–29, 1948. Assuming a mean mortality rate of larvae in Lower Little Egg Harbor of 97.4 per cent (Table IX) from predators and from a small degree of tidal exchange, 72 larvae per 100 liters of sea

Table IX

Rate of disappearance of clam veligers from the plankton of Little Egg Harbor.

EARLY STAGES IN PLANKTON			LATE STAGES IN PLANKTON			Percentage survival of larvae
Date	Length range, μ	No. per 100 liters	Date	Length range, μ	No. per 100 liters	
July 30, '48	98–127	2,780	—	—	—	0
Aug. 10, '48	100–115	240	Aug. 18	180–196	20	8*
July 6, '49	98–140	2,100	—	—	—	0
June 25, '50	100–113	800	June 30	185	2	0.3*
July 7, '50	107–133	3,300	July 11	160–193	36	0.1*
July 19, '50	93–117	112	July 25	175–187	8	7*
July 12, '51	98–100	67,000	—	—	—	0
July 13, '51	104–114	34,000	—	—	—	0
July 23, '51	115–130	6,000	July 28	182	1	0.02*
July 24, '51	115–135	1,630	July 29	182–198	1	0.06*

Mean of * 2.6.
Over-all mean 1.6.

water of the original 2,780 larvae per 100 liters would reach setting size. During the last six days of planktonic existence of the swarm a total of 3.96 inches of rain fell, resulting in addition of rain water to the bay equivalent to about 10 per cent of the mean high-tide volume of Little Egg Harbor. Dilution by rainfall to this degree, assuming rather rapid mixing of fresh water with the bay water, would result in a decrease in density of the larvae which were ready to set from 72 larvae per 100 liters to about 65. But more important, during the latter portion of the planktonic existence of the swarm, tidal amplitudes increased from 1.4 to 2.7 feet, augmenting exchange from about 24 to 42 per cent. Although the data do not permit calculation of the quantity of loss of larvae by exchange, such large increases in exchange, compounded to a small degree by flushing, may well provide on explanation for much of larval loss.

It is evident from these observations that the strong tendency of *M. mercenaria* to spawn more frequently and to produce densest swarms of larvae during neap tides in Little Egg Harbor has probably contributed to a retention and high degree of survival of the species in this bay.

DURATION OF PLANKTONIC STAGE OF *M. mercenaria* IN LITTLE EGG HARBOR. On June 25, 1950, a moderately dense though widespread single swarm of early straight-hinged veligers appeared on the late flood tide at Station 4 (Fig. 26). No other spawnings occurred in this area in June; it was therefore possible to follow growth of individuals in daily samples of the single swarm and determine duration of the planktonic stage. The swarm was accompanied by low to moderate tidal amplitudes and very little rainfall (Fig. 15: 1950), which probably accounts for survival of a small proportion of the population to setting size. In typical fashion, the density of larvae in the daily plankton samples decreased rapidly with time (Fig. 31) from a maximum of about 800 to a minimum of two larvae per 100 liters. Growth rate, indicated by the length of the most abundant size group of larvae in each plankton sample, was rapid. The largest larvae reached a length of 185 μ in seven days from the time of fertilization of ova, paralleling the most rapid rates expressed by larvae cultured in our laboratory and almost those in that of Loosanoff and associates (1951b), who have obtained a minimum setting time of six days. Extrapolation from the growth curve in Figure 31 shows that these larvae grew to a setting size of approximately 200 μ in eight days in native waters. Median daily water temperatures ranged from 23.4° to 26.2°C. and mean daily salinities from 30.4 to 31.4 $^{0}/_{oo}$ during the larval period (Fig. 31).

The length of abundant size groups of larvae was determined for most samples collected for the remainder of the summer of 1950. Growth curves represented by these parallel rather

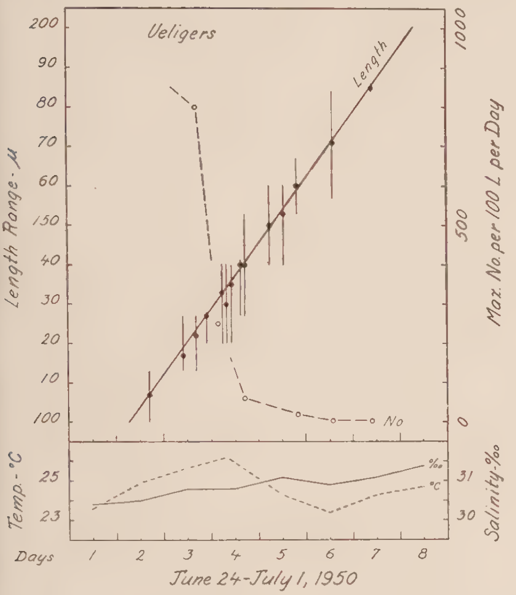


FIG. 31. Rate of growth and of disappearance of veligers of *M. mercenaria* in a large, single, widespread swarm appearing in the central basin of Lower Little Egg Harbor (Stations 2–4) on June 25 (spawned June 24), 1950 (compare with Figure 26), showing length range in vertical lines; and most abundant size group of larvae in solid circles. Connected open circles represent maximum densities of swarm from day to day. Accompanying temperature (median daily) and salinities (average of surface and bottom) are given in bottom figure.

closely the growth curve of the population spawned on June 24 (Fig. 26). This same population was accompanied by relatively high water temperatures, which accelerated larval growth rates. In contrast, the population spawned in late July of the same summer was confronted with rapidly dropping temperatures which slowed growth rate and prolonged the veliger period. These growth curves, as did those of Loosanoff et al. (1951b) for larvae grown in the laboratory, approximate straight lines.

HORIZONTAL AND VERTICAL DISTRIBUTION OF CLAM LARVAE. Older stages of planktonic larvae of a few species of estuarine animals—the eastern oyster *Crassostrea virginica* (Nelson and Perkins, 1931; Carriker, 1951; Pritchard, 1951; Manning and Whaley, 1954) and the barnacles *Balanus improvisus*, *B. crenatus*, and *B. balanoides* (Bousfield, 1955)—tend to concentrate in lower, more saline strata of sea water and are thereby transported passively up the estuary in the net nontidal upstream flow (Pritchard 1952). Hulburt (1957) has shown that both larvae and adults of the planktonic shrimp *Neomysis americana* behave in a similar manner. In the case of the oyster and the barnacles, larvae may thus set some distance up the estuary from spawning parents. The eastern oyster is the only mollusk in which ecological studies of this kind have been reported; our investigations in Little Egg Harbor provided an opportunity to extend observations of vertical and horizontal movements of mollusk veligers to the hard clam.

The most striking feature of the horizontal distribution of veligers of *M. mercenaria* in Little Egg Harbor was its unevenness. Following occasional widespread spawning of adults during the early part of the summer, larvae were encountered at all stages of the tide throughout Lower Little Egg Harbor and the lower reaches of tributary tidal creeks. Maximum densities were found in the region around Stations 3, 4, and 8. During the summer of 1948 a maximum of 2,780 early straight-hinged larvae per 100 liters of sea water was taken there; in 1949 this maximum was 3,800; in 1950, 3,500; and in 1951, 67,200. Densities decreased progressively, though quite irregularly, toward Manahawkin Bay, Tuckerton Creek, and Beach Haven-Little Egg Inlets.

Low larval densities near inlets resulted in part from the diluting effect of tidal exchange. That larvae from the lower areas of Lower Little Egg Harbor were transported out of the bay was demonstrated on August 8, 1950, when we collected a vertical series of plankton samples at hourly intervals from late ebb tide through the subsequent flooding tide to flood slack at Station 10 in the inlet. During this 7.5-hour interval, the ranges of mean vertical water temperatures and salinities were 0.7°C. and 0.5 ^{o}/oo respectively, suggesting the homogeneity of the water mass. The first high tide of the day was 0.35 feet below mean high water (Table VI), and about 30 per cent of the bay water emptied into the ocean during the ebbing tide. During late ebb and early flood tide an average of 0.2 late umboned veligers was present per 100 liters, whereas no larvae were encountered during mid and late flood tide. The previous day at mid ebb tide an average of 35 late umboned clam larvae per 100 liters was taken in a vertical series of plankton samples pumped at Station 4. A second series at the same station and at the same phase of the tide on August 9 disclosed that the average density of late umboned veligers had dropped to 21.

After limited localized spawning of small segments of the clam population in the bay, larvae appeared in small swarms of variable densities and could be detected as they passed Station 4 in the tidal flow. Individual swarms could often be followed from day to day at this station by sampling at approximately the same phase of the tidal cycle.

In the laboratory a small rise in water temperature will stimulate a few male hard clams to emit spermatozoa when they are physiologically ready to spawn, and the double stimulus of temperature and sperm will bring on spawning of other similar individuals in the same water, resulting in a dense suspension of gametes. Although not actually observed in the field, this behavior can be attributed to populations in the bay to explain the grouping of larvae in swarms. Thermal stimulation of a few males in the bottom will induce release of sperm, which in turn will cause other males in the close vicinity to spawn; in a few minutes females will commence discharging ova. Soon tidal flow will spread over the bottom a cloud of gametes which will be transported through the distance of the tidal excursion. If the few initiating male spawners are widespread across the main axis of tidal circulation in the bay, and clams are generally ready to release gametes a mass spawning of baywide dimensions will occur. During the early part of the season when most abundant spawnings took place, we did encounter such widely distributed swarms of larvae of relatively uniform size in Lower Little Egg Harbor. Later in the summer, spawning in the laboratory was obtained with more difficulty and in limited quantities, and correspondingly smaller localized larval swarms occurred sporadically in the bay. Thorson (1950) states that it may be considered a biological rule that among invertebrates which shed their eggs and sperm freely in the water, the males are the first to spawn and thus stimulate the females to shed their eggs; these, having been shed directly into a suspension of sperm of their own species, have especially good chances of being fertilized.

We collected and studied a total of 97 vertical series of plankton samples over the period of four summers in Little Egg Harbor and tributaries, each series consisting of from three to six vertical samples equally spaced from surface to bottom. Most samples were pumped at Station 1 in Ezras Creek and at Station 4 in the open bay (Fig. 14). In this way it was possible to contrast distribution and movements of veligers in a shallow, narrow tidal creek with that in the open bay. Data on distribution were analyzed in three ways:

I. The first analysis is based on a study of plots in the form of polygons of representative vertical series of veliger densities and accompanying physical data (Figs. 32–35). Of

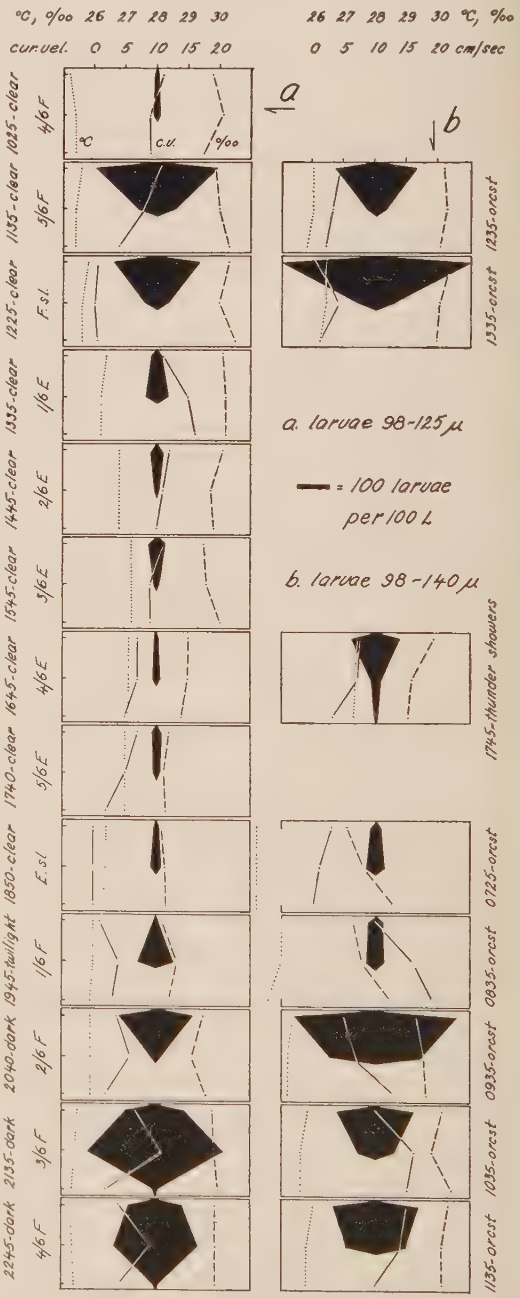


FIG. 32. Vertical distribution of straight-hinged veligers of *M. mercenaria* at approximately hourly intervals through the cycle of two separate tides at Station 1 in the middle of Ezras Creek, Little

the several series of vertical plankton samples pumped through the cycle of a tide at Station 1, those on July 26 (Fig. 32a) and July 27, 1948 (Fig. 32b), contained maximum concentrations of straight-hinged veligers and are representative of veliger distribution and movements in the creek. Characteristically, very few umboned larvae were found there. Maximum densities appeared during the late flood tide, the higher evening tide of July 26 bringing high larval concentrations earlier in the tidal cycle than the lower morning tide, as water from the lower portion of the central basin entered the creek. Densities decreased rapidly in the course of the ebbing tide, presumably because of inroads of bottom-dwelling filter-feeding predators. The polygons suggest that during daylight hours and while creek water was ebbing and flooding swiftly, maximal larval densities remained near the surface. As current velocity decelerated during daylight hours, these dropped to about mid-depth, only to rise surfaceward again as tidal movement accelerated. Early veliger stages of *Crassostrea virginica* likewise ascend into surface layers concomitant with maximal current velocities of flood and ebb tides (Carriker, 1951). I would like to suggest that turbulence resulting from the movement of sea water in the irregular creek channel was the stimulus which promoted their surfaceward climb. As here employed, turbulence refers to the state in which random motion of smaller or larger masses of sea water is superimposed upon the general pattern of flow (Sverdrup et al., 1942). Soon after darkness fell (3/6 and 4/6 F. Fig. 32a), the zone of maximum larval density shifted to midstream, and a significant number of larvae were collected near the bottom in spite of strong currents and in contrast to the surface position of maximal densities at similar phases of the tide during daylight hours on July 27 (Fig. 32b). This distributional pattern suggests that at night the larvae, no longer attracted toward the surface by light, assumed a broader vertical distribution and in addition sought the zone of maximum current velocity (turbulence?) at midstream. In a total of thirty-four vertical series of plankton samples collected in the creek during daylight hours, larvae were encountered near the bottom in only three, and in these only in negligible numbers. No explanation is available for this, except for one (1745, July 27, Fig. 32b) taken shortly after a severe thunderstorm in which conditions accompanying the storm may have sent a few of the veligers bottomward. In contrast, Quayle (1952), in a preliminary study of vertical distribution of veligers of the clam *Venerupis pullastra* in Fairlie Channel, Scotland, found the larvae widely distributed in depth during the day but concentrated near the surface at night. In his study of the distribution of the veliger larvae of *Ostrea edulis* in the Oosterschelde, Holland, Korringa (1940) observed that vertical distribution of the larvae appeared to be uninfluenced by light, water temperature, wind and wave action, and current velocity, larvae remaining more or less uniformly distributed vertically under these conditions. And Carriker (1951) and Manning and Whaley (1954) report that older veliger stages of *Crassostrea virginica* occur in maximal densities at progressively greater depths as they approach the pediveliger stage. Since the larvae of *M. mercenaria* appear able to swim faster than the vertical water currents and to some degree maintain a vertical position, it is probable they are also concentrated horizontally by typical water movements (Pomeroy et al., 1956; Ragotzkie et al., 1953).

At Station 4 in Little Egg Harbor maximal larval densities were frequently found during the late flood and early ebb tide (Figs. 33, 34). As in the creek, during daylight hours larvae were generally absent near the bottom. Two exceptions to this were met in a total of 53 vertical series of plankton samples pumped at all stations in the central basin of the bay.

Egg Harbor, N. J.: left, 1025 to 2245, July 26; right, 0725 to 1745, July 27. Hour indicates the mid point in sampling interval for each vertical series. The study of July 26 was extended into the evening to include effect of darkness on larval distribution; collecting at 1745 in the study of July 27 was done during a thunderstorm. For each vertical series there are shown the density of veligers at surface, middle, and bottom and accompanying temperature, salinity, and current velocity of the water as well as approximate quantity of light (degree of cloudiness of the sky, and whether day or night). The breeze on July 26 was moderate (Beaufort Scale of Winds No. 4) throughout the day, and the interval of time for collecting all data at each vertical series of three strata ranged from seven to ten minutes; on July 27 the breeze ranged from calm to light (Beaufort No. 0–1), and interval of time for collecting data at each vertical series ranged from six to nine minutes. The depth of water at the point of sampling on July 26 ranged from 1.3 m. at ebb slack to 1.8 m. at flood slack; and on July 27, from 1.1 m. to 1.7 m. Data for July 27 are plotted so that stages of the tide coincide with those of July 26; the vertical series for 1/6–3/6 E were omitted on July 27.

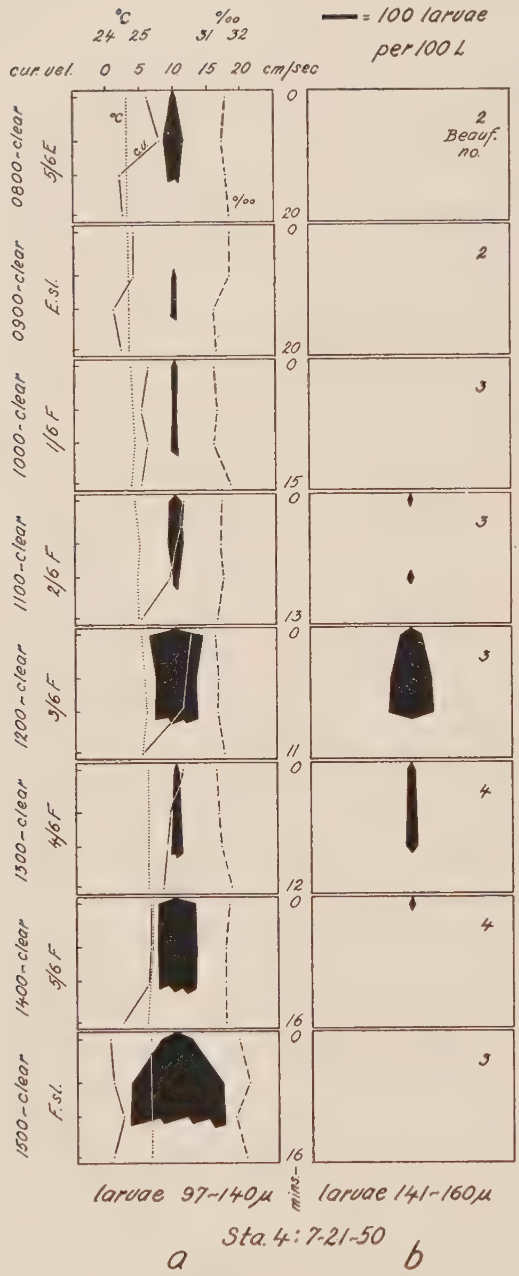


FIG. 33. Vertical distribution of straight-hinged (left) and umboned (right) veligers of *M. mercenaria* at hourly intervals through two-thirds of a tidal cycle in Little Egg Harbor, N. J., during daylight. Larvae were sampled at four equally spaced strata from surface to bottom. Accompanying data on water temperature, salinity, current velocity, condition of the sky, intensity of the wind, and duration of sampling interval for each vertical series (between columns of rectangles) are shown. The depth of water at the sampling point ranged from 2.3 m. at ebb slack to 2.9 m. at flood slack tide. Densities of straight-hinged veligers in bottom strata were not recorded because of excessive quantity of sediment in the plankton samples.

No interpretation is available for the first (Fig. 34: 5/6 F–1245, 8–4–50, Sta. 4); the second, found at Station 8 (Fig. 34, top rectangles), may be due to location of the station in a region characterized by a complex pattern of currents. Main larval concentrations in the bay, in contrast to those in the creek, occurred principally somewhere in the middle of the vertical column regardless of the stage of the tide. Possibly the lower turbulence in the bay than in the creek may account for this. The apparent exception noted in the top set of rectangles in Figure 34 may be explained by the fact that these samples were collected in a water mass which had just passed through channels among islands leading to the central basin (Fig. 14), and the larvae in these channels behaved as they would have in the creek. During hours of darkness in the bay, veligers were generally distributed rather uniformly from surface to bottom (Fig. 35). In a total of seven vertical series of plankton samples pumped there at night, a single exception was noted (top right rectangle, Fig. 35). Whether this is attributable to sampling during slack water rather than during periods of tidal flow is not known. Because of the vertical uniformity of temperature and salinity in the bay and in the creek, no effort was made to associate vertical distribution of larvae with these factors.

II. In the second analysis of the data, larval density at each stratum was converted to percentage of total larvae in its respective vertical series, and vertical series were grouped according to location, early- and late-stage larvae, stage of the tidal cycle, wind velocity, and relative intensity of light. The mean percentage of larvae in each vertical stratum was then calculated for each group, and these percentage means were plotted for ease of interpretation. Although the significance of the results obtained by this kind of analysis may rightly be questioned, it is worth noting that the results tend to support those of the first analysis (Figs. 32–35) and to suggest additional trends. Whereas in the creek larvae rose surfaceward on the early flood and early ebb and dropped to the middle again on the late flood and ebb, these relationships were less clear in the bay: there larvae appeared to rise on the early flood, straight-hinged ahead of umboned larvae, then to sink slowly to the middle stratum throughout the remainder of the flood and ebb tide. Further, as wind velocity increased in the bay during daylight hours, veligers seemed to rise vertically, straight-hinged preceding umboned stages. This relationship, if real, may again indicate a response of larvae to augmented turbulence of the water, in this instance brought about by wave action. As light intensity diminished in the bay, larvae appeared to move surfaceward, then spread somewhat uniformly throughout the vertical column from surface to bottom. In the creek, possibly because of greater turbulence there, maximal densities fluctuated between midstream and surface throughout day and night according to the stage of the tidal cycle, and only a few larvae moved near the bottom during darkness.

III. The third treatment of the data was by the analysis of variance of larval densities. To perform an analysis of variance we assume a linear model of the form log $(y + 1) =$ (factor 1) $+$ (factor 2) $+ \ldots +$ (factor k), where $y =$ the number of veligers per 100 liters of sea water. This transformation was made in the hope that log $(y + 1)$ would provide a scale on which the various environmental effects would be additive, and the deviations from the model would have approximately a normal distribution. Similar transformations have been made by Winsor and Clark (1940).

The following factors were considered in the equation used in analyzing the data for both the straight-hinged and umboned larvae:

1. Stage of the tidal cycle: 12-hour intervals.
2. Time of day: 0400–0700, 0700–1700, 1700–2000, 2000–0400.
3. Depth of vertical samples: equally spaced between surface and bottom; in deeper water: surface, upper middle, middle, lower middle; and in shallower water: surface, upper middle, lower middle (bottom samples were excluded since so few larvae were taken there).
4. Wind velocity: calm, light, moderate, strong (Beaufort Nos. 0–1, 2–3, 4, 5).
5. Light: degree of cloudiness of sky (one-third, two-thirds, and fully overcast; twilight); and darkness (nighttime).
6. Location of Stations 1, 3, 4, 5, and 8.
7. Interactions of (a) relative intensity of light, (b) relative wind velocity, (c) stage of the tidal cycle, and (d) day and night, with depth.
8. Current velocity.

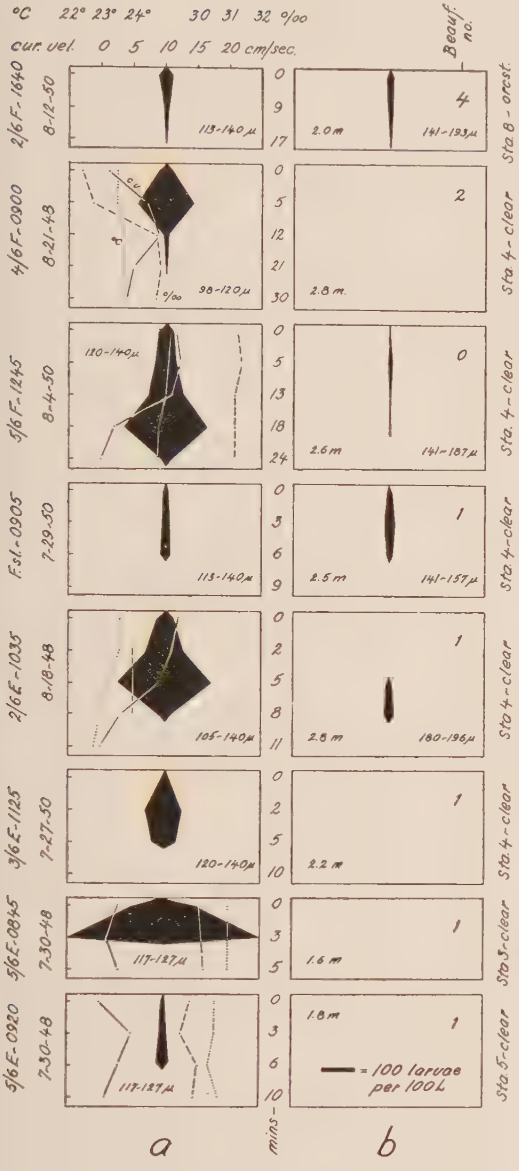


FIG. 34. Vertical distribution of straight-hinged (left) and umboned (right) veligers of *M. mercenaria* in a series of isolated vertical studies made at different stations in Little Egg Harbor, N. J., during daylight and arranged in the natural sequence of the stages of the tidal cycle. Larvae were sampled at equal intervals from surface to bottom. Each vertical series is identified by station number and hour and date the sample was taken. Where available, accompanying data on water temperature, salinity, current velocity, condition of the sky, intensity of the wind, duration of sampling interval for each vertical series, and range of length of larvae are indicated. (The density of straight-hinged veligers in the "5/6 E–0845" vertical series is approximately five times that indicated by the density scale). The depth of water at sampling time is given in meters at the lower left in each of the righthand rectangles.

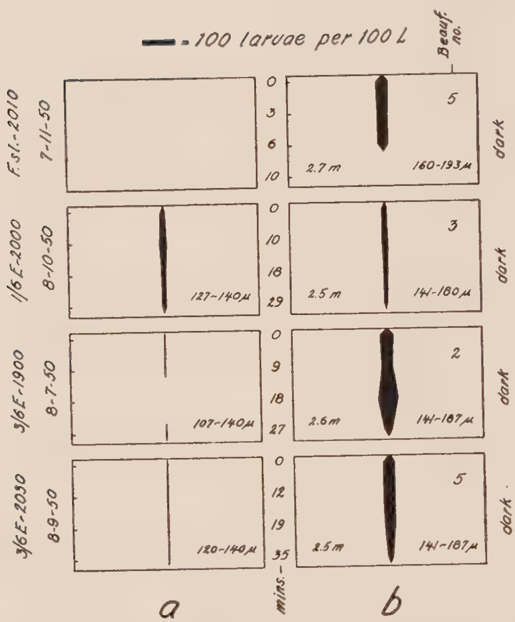


Fig. 35. Vertical distribution of straight-hinged (left) and umboned (right) veligers of *M. mercenaria* in a series of isolated vertical studies made at Station 4 in Little Egg Harbor, N. J., at night. Larvae were sampled at equal intervals from surface to bottom. The intensity of the wind, duration of sampling interval for each vertical series, range of length of larvae, and depth of water at sampling time are indicated.

The basic assumption drawn in formulation of the equation, that effect of environmental factors is approximately additive, is verified by the fact that no interactions were found to be significant. The assumption of normality of the deviations from the model was investigated by the *chi*-squared test of goodness of fit. For the early stage larvae, *chi*-squared with 11 degrees of freedom was 8.74 which indicated close agreement with the hypothesized normal distribution. However this was not the case with the late-stage larvae. A histogram of the deviations showed a long tail on the right—a result of the fact that many of the catches were zero in number. Many investigations have been made of the effect of nonnormality on inferences made from the analysis of variance. Scheffé (1959) shows that inferences about means are not seriously upset by nonnormality. Fortunately in this investigation no cases of borderline significance were encountered. Thus it is unlikely that more than the expected number of errors in inference will be made. It should also be emphasized that ecological relationships which are not statistically significant according to this statistical analysis may in reality be significant, but obscured by treatment of the data or insufficient information. However, any that are found are not likely to be artifacts. It is for this reason that interpretation of plots of hour-to-hour distribution of larvae with reference to accompanying environmental factors was presented in the first analysis.

Results of the statistical analysis may be summarized as follows. Appearance of maximal larval densities in the creek during the late flooding tide is statistically significant ($p < .01$) and confirms what is shown in Figure 32; the water which enters the creek at this period of the tidal cycle bears high concentrations of veligers from the lower portion of the central basin of the bay. Also significant, though unexplained, is the increase in density of larvae in the creek as the relative intensity of light decreased during the day ($p < .01$). Taken as a whole, the analysis suggests that the stage of the tide, current velocity, relative quantity of light during daylight hours, and time of day had no significant influence on the vertical distribution, except for the bottom stratum, of the larvae in the creek. However, the detailed hour-to-hour study reported in Figure 32 shows trends not found significant by this method of analysis.

Appearance of maximal concentrations of straight-hinged veligers in the bay at Station 4 during the late flood and early ebb is statistically significant ($p < .01$); in contrast, umboned larvae were more or less uniformly distributed throughout the tidal cycle (Fig. 36). This observation finds support in the fact that the maximum density of spawning parents was located in the lower part of the central basin, and it suggests that spawning probably occurred during late ebb or early flood. It further suggests that early-stage larvae tended to remain in the original swarms resulting from mass spawning by parents, and in time, as a result of the hydrographic mixing processes, late-stage larvae became widely and rather uniformly dispersed and no longer exhibited noticeable peaks of concentration within the excursion of a tidal cycle

The linear effect of degree of overcast of the sky on horizontal distribution of larvae in the bay was not significant. Yet the time of day provided a large and statistically significant correlation with larval density (Table X) ($p < .01$). Maximum densities (expressed as geometric means) of straight-hinged veligers were encountered in the daylight period of 0700–1700, whereas most umboned larvae were

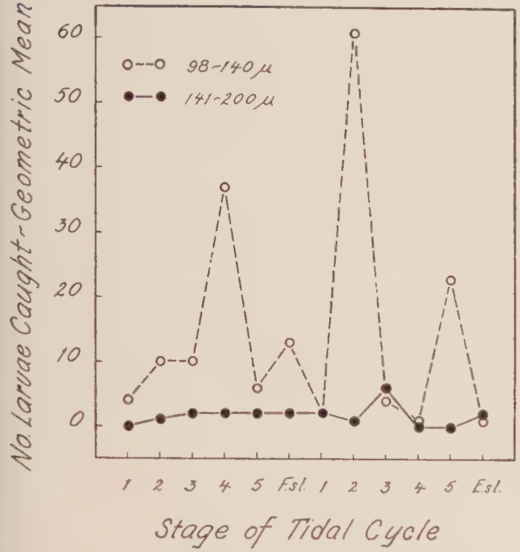


FIG. 36. Geometric means of the total number of straight-hinged and umboned veliger larvae of *M. mercenaria* caught at all depths—day and night—at each stage of the tidal cycle during the study in Little Egg Harbor, N. J.

found during hours of darkness. No data are available which indicate that bivalve veligers may spend a part of the twenty-four-hour period at rest on the bottom, while Gaarder and Bjerkan (1934) have shown that veligers of *Ostrea edulis* raised in Norwegian oyster pools must remain entirely off the bottom because of the lack of oxygen and presence of high concentrations of hydrogen sulfide there.

Table X

Geometric mean of number of veligers of *M. mercenaria* per 100 liters collected in Little Egg Harbor, N. J., during different periods of the day.

Hours	No. of samples	Straight-hinged veligers	Umboned veligers
0400–0700........	3	4	0
0700–1700........	144	12	1
1700–2000........	21	5	7
2000–0400........	9	1	9

And Dew and Wood (1955) found bivalve larvae (chiefly *Crassostrea commercialis*) more dense in statistically significant quantities in both surface and deep tows at night than during the day in Sydney Harbor, Australia. It would seem that differences in vertical distribution of larvae in both Little Egg Harbor and in Sydney Harbor during day and night and sampling at constant vertical strata may account for this apparent diurnal density variation.

Increasing wind velocity had no apparent linear influence on density of straight-hinged veligers at Station 4, but there was a statistically significant increase in the density of umboned larvae with increase of wind velocity ($p < .05$). This apparently anomalous circumstance is explained by the fact that prevailing winds, and particularly moderate to strong ones, in the Little Egg Harbor area during the summer moved up the bay from the southwest (Fig. 14), forcing masses of water bearing umboned larvae toward Station 4. The difference in distribution between early- and late-stage larvae may suggest that older stages tend to be transported down the bay as they develop. If this hypothesis is valid, a response of veligers to migrate surfaceward under the double stimulus of turbulence and light and the presence of even very slight nontidal surface water seaward would provide a mechanism by means of which veligers could be transported seaward as they approach the pediveliger stage. The daylight period is longer than nighttime in the summer in Little Egg Harbor, and winds are present often over much of the twenty-four-hour period. The vertical uniformity of salinity and water temperature in the bay precluded a study of the influence of these factors on vertical distribution, but does not exclude the possible presence of weak nontidal circulation (Pritchard, 1952). These problems merit further study.

The degree of cloudiness of the sky during the day had no statistically significant effect on vertical distribution of the larvae.

An analysis of the over-all mean vertical distribution of veligers in vertical series collected in the bay under all conditions (geometric means, Table XI) suggests that maximum density occurred in the middle zone for the straight-hinged veligers, and that umboned larvae were rather uniformly distributed in the vertical column except for the bottom stratum. Even though the geometric mean of number of veligers in the bottom stratum of both early and late stages is 1, most samples did not contain larvae of either stage. However, the vertical variation of density of straight-hinged larvae shown in the table is not statistically significant. This is surprising and may be accounted for by the facts that (a) the number of samples at the middle stratum is relatively small; and (b) five of the eleven samples

Table XI

Geometric mean of number of veligers of *M. mercenaria* per 100 liters collected in different vertical strata, day and night, in Little Egg Harbor, N. J.

Depth	No. samples at each depth	Straight-hinged veligers	Umboned veligers
Surface	58	8	2
Upper middle	54	11	2
Middle	11	33	1
Lower middle	54	7	2
Bottom	58	1	1

Table XII

Geometric mean of number of veligers of *M. mercenaria* per 100 liters collected in different vertical strata during daylight hours (0700–1700) and during evening hours (1700–2000; 2000–0400).

Depth	No. samples at each depth	Straight-hinged veligers	Umboned veligers
0700–1700			
Surface	47	10	1
Upper middle	44	15	1
Middle	10	35	1
Lower middle	43	10	2
Bottom	47	1	0
1700–2000			
Surface	7	4	6
Upper middle	7	6	8
Lower middle	7	4	9
Bottom	7	1	2
2000–0400			
Surface	3	1	9
Upper middle	3	0	11
Lower middle	3	1	8
Bottom	3	1	2

were taken during 4/6 flood and 2/6 ebb tide, which were tidal stages of maximum larval densities, and ten of the eleven samples were collected during the time interval 0700–1700, which was also a period of high larval densities. It should be noted that plots of representative vertical series in Figure 34 likewise point to maximum larval concentrations somewhere in the middle stratum. The stage of the tide, current velocity, relative intensity of light during the day, and wind velocity had no significant influence on the vertical distribution of the larvae (exclusive of the bottom) in the bay. But the time of day (and concomitantly, the effect of day and night) did appear to have some effect on the vertical distribution of umboned veligers in the bay (Table XII). They appeared to remain rather uniformly distributed above the bottom during daylight hours and to move bottomward during twilight and hours of darkness. This supports the polygonal plots of distribution in Figure 35. Straight-hinged veligers, as also shown in Table X, tended to concentrate near the middle stratum, at least during daylight and early evening hours. These observations would indicate that the larvae are able to control their vertical distribution to some degree, possibly seeking a certain range of light intensity during the day, and are more than passive buoyant particles in the water (Turner, 1953).

In summary, these three analyses of vertical distribution of veligers of *M. mercenaria* suggest the following possible trends: (1) Veligers seem to maintain themselves in the water throughout the planktonic existence, generally away from the bottom and bottom-dwelling predators during daylight hours; they are more broadly distributed (descending bottomward, especially the umboned stages) during hours of darkness. This raises the question whether pediveligers may set most frequently at night. The major concentration of straight-hinged larvae in the middle strata during daylight hours may indicate that they are attracted to an optimum light intensity in that zone, whereas at night this stimulus disappears and larvae then mix more uniformly throughout the column. (2) Veligers may be stimulated to rise in the water column under the stimulus of turbulence created by tidal currents and wave action. This behavior would make possible differential horizontal migrations in the presence of net nontidal estuarine circulation. Laboratory experiments of Turner and George (1955), which showed that hard-clam veligers are blocked in their vertical movement through a gradient of salinity by the 15 ^{0}/oo stratum, suggest a means by which larvae may move up the estuary in the presence of low surface salinities. Where a halicline at the 15 ^{0}/oo level coincided with the vertical level of no net motion of horizontal estuarine circulation, it would appear that larvae would remain entirely within the bottom net up-estuary flow.

Thorson (1950) emphasizes the point that young pelagic larvae of marine invertebrates (except those whose adults live in the intertidal zone or near the surface) are positively phototactic, while old larvae approaching metamorphosis are negatively phototactic. Thus larvae spend their pelagic existence in the free water masses near the illuminated-phytoplankton-producing strata near the surface, while metamorphosing larvae, because of their photonegativity, are forced toward the bottom to the substratum, where they will settle. Thorson's observations suggest that the vertical distribution of veligers of *M. mercenaria* may be explained in part as a response to distribution of food organisms; at present there is no information on this interesting point.

The field studies on distribution reported here are of a preliminary nature. Although we collected many samples, vagaries of the weather, erratic temporal and horizontal distribution of the larvae in the bay, and short duration and precipitous loss of veligers during the planktonic existence all militated against a more productive sampling design of larval populations. In addition to providing some suggestions on larval ecology of *M. mercenaria* in the field, we hope that these studies will stimulate a more rigorous approach to such studies in the future. With the assistance of modern technology it should be possible to devise and employ a series of multiple plankton samplers by means of which larval populations and pertinent environmental factors could be sampled simultaneously at a number of vertical strata in several different stations along the long axis of an estuary at half-hourly intervals during the cycle of many tides when dense larval swarms are in the water. Comparative investigations in a variety of estuaries and embayments would contribute additional valuable information.

Pediveliger and Byssal Plantigrade Stages in the Laboratory

Pediveligers are extremely active. After the foot is formed, they display it as they swim, extending it periodically between the valves, possibly in an attempt to contact the substratum. Larvae ranging in length from 170 to 220 μ were observed exhibiting this behavior. On the bottom pediveligers creep smoothly over the substratum for a while, moving back and forth in what looks like a searching pattern, then suddenly extend the velum, swim off to a different site, settle to the bottom, and continue crawling in a zigzag trail. Alternation of swimming and creeping may represent the animal's search for favorable setting surfaces, and the capacity to swim during this stage extends widely the territory which it can examine (Turner, 1953; Turner and George, 1955).

RESPONSE TO CONTACT. In 1951 we experimented to determine the attraction of a number of selected solid substrates and sediments of varying particle size to setting pediveligers. The following surfaces were placed on the plunger plate and on the bottom of mass larval cultures as larvae approached the pediveliger stage: (a) clean glass (small watch glasses); (b) clean, smooth, bleached oyster shell (*Crassostrea virginica*) and clam shell (*Mercenaria mercenaria*); (c) glass surfaces (microscope slides) dipped in melted paraffin and sprinkled with varying quantities of fine sand; (d) clean, bleached oyster and clam shell deeply excavated by the boring sponge *Cliona;* (e) deeply pitted leached slag; (f) small watch crystals in which detritus (microscopic fecal pellets, unconsolidated organic fragments, and some silt) had accumulated; (g) small watch crystals filled to varying depths with fine bay sand washed and screened through Screen No. 60; (h) similar watch crystals containing coarser sands. To find newly set plantigrades in fine sediment with a minimum of fatigue we used bright direct sunlight and a binocular magnification of about 25X.

No pediveligers affixed on surfaces placed on the plunger jar plates, probably because of the slow vertical movement of the plates. All setting took place on or near the bottom of culture jars. A few clams attached to the under side of some slightly elevated shells, but by far the majority affixed to the upper surfaces of materials provided. This observation supports Quayle's (1952) statement that most noncementing species prefer to settle on upper surfaces. Although setting in significant densities occurred in dishes partly filled with sand and in pits in slag and shell, densest sets were found on surfaces covered with detritus. In a watch crystal coated with a thin layer of paraffin and sand, the only detritus present at the time of setting had been incorporated in a worm case by a polychaete which had set in the dish; all clams in the dish attached to the worm case. Shells on the bottom of one of the mass clam cultures were coated with varying thicknesses of detritus; attached clams were most dense on shells bearing the thicker layers of detritus. On pitted slag and shell, pediveligers accumulated most densely in the pits, where sediment also accumulated most deeply, trapped by the quiet pockets of water in the pits. In many pits pediveligers were packed so densely that no others could have entered. It was apparently not so much depressions that attracted pediveligers as sediment: slag coated with detritus bristled with clams, which were equally dense in detritus-filled pits and aggregations of detritus on open surfaces of the slag. Turner and George (1955) report that young byssal plantigrades of *M. mercenaria* in their laboratory likewise affixed in clumps of detritus and suggest that young clams prefer an upright position facilitated by the presence of detritus. Quayle (1952) found that young of *Venerupis pullastra* also settle on surfaces layered with detritus.

Where the depth of sediment did not greatly exceed the length of byssus and plantigrade combined, plantigrades affixed the byssus to the underlying solid surface and then remained suspended in the overlying sediment near the surface. In deeper sediment the majority affixed to glass around the inner surface of the dish and slightly below the surface level of the sediment; a minority, to grains of sand in the sediment. Plantigrades reared in the absence of sediment on the bottom of the container soon become coated with accumulating detritus, while those burrowing within sediment remained clean and smooth as a result of movement through the substrate.

These observations suggested that byssal plantigrades possess a strong thigmokinetic response. This hypothesis was supported by further preliminary experiments. With no exception those placed in clean dishes devoid of sediment attempted with continuing persistence to "dig" the distal tip of the foot into the glass. In a second experiment a population of plantigrades 0.2 to 0.4 mm. in length was maintained without sediment for eight days. These clams were then transferred to a petri dish in which the bottom was covered with a thin, uneven layer of clean sand; the sand particles ranged in diameter from 10 to 120 μ. The bivalves soon began crawling actively and randomly about, snaillike, through the shallow sand, and more vigorously than on a clean glass bottom alone, until deeper sand was encountered. They continued creeping through sediment until the valves were well covered, then stopped crawling and attached. The same plantigrades, when placed in a dish with larger particles of sand (about 400 μ in diameter), crawled less actively and attached less readily than in the fine sand, suggesting that a sediment of particle size smaller than the plantigrade is more suitable than larger particles for affixation. In this connection de Blok and Geelen (1958) demonstrated that newly metamorphosed *Mytilus edulis* show a decided preference for threadlike materials as attachment substrates for the byssus, and with increase in size the mussels select threads of larger diameter. Plantigrades which had attached to firm substratum under shallow sediment, when uncovered by removal of sediment by gentle flushing with a stream of water, quickly released the byssus and began creeping.

In the absence of suitable sources of contact stimulation plantigrades aggregated and received contact stimulation from each other. In a third experiment we placed some 50,000 plantigrades ranging in length from 0.2 to 0.5 mm. in a clean finger bowl in shallow sea water. Within an hour the majority had gathered in grapelike clusters and attached to the bottom and to each other. Hunter (1949) reports a similar strong contact response in byssal plantigrades of the rock-boring bivalve *Hiatella;* Morton (1960) makes the same report of adult *Lasaea rubra.*

These observations and experiments suggest that plantigrades of *M. mercenaria* set most abundantly in fine sediment containing appreciable quantities of organic detritus. It was not possible to determine the relative attractiveness to plantigrades of graded series of grain sizes of different kinds of organic and inorganic sediment. This should prove a profitable avenue for future research.

RESPONSE TO LIGHT. Whenever light reflected from the northern sky was directed on plantigrades (lengths ranging from 0.2 to 1.3 mm.) in a dish without sediment in the laboratory during clear days, the animals became restless, and many started crawling randomly about, their behavior suggesting a strong negative photokinetic response at this illumination. Measuring external dimensions of these young clams under a binocular microscope was therefore difficult because the light stimulated locomotion. On the average, locomotory activity was stimulated about 30 seconds after light was directed on the animal. Plantigrades buried under fine clean sand also became active when light was directed on them, the most exposed animals expressing the most activity. Plantigrades buried more deeply in sediment (particularly in dark grains) were affected less or not at all by the light.

During the summer of 1956 we were able to examine this response more quantitatively. About 500 very active, rapidly growing plantigrades which ranged in length from 0.4 to 1.3 mm. were placed several layers deep within a circle two cm. in diameter in the center of each of two 6 cm. petri dishes, in sea water (of salinity 35.0 $^{0}/oo$, temperature 27°C.) 5 mm. deep. One dish, the control, was set aside in the dim light of the laboratory (heavily overcast day, with no laboratory lights on). The experimental dish was placed on the glass stage of a binocular microscope and a beam of light from a microscope lamp, cooled through a water cell, was directed under the clams by a flat substage mirror; 700 foot-candles struck the animals. A mask with an opening 5.5 cm. in diameter under the petri dish provided a narrow shaded zone around the edge of the dish. Light was most intense in the 2-cm. circle in the center of the 5.5-cm. lighted circle and graded into dim light peripherally. Almost as soon as light struck the clams, they started crawling about randomly, the general direction of movement being outward away from the center of the light. In ten minutes half the clams had crawled out of the 2-cm. circle of bright light; in twenty minutes most of the clams had left and concentrated in the dimmer peripheral light; a few crawled to the outer dark confines of the dish. In the control dish at the end of the twenty-minute period, the plantigrades remained aggregated in the center of the dish; only a few had moved outward about 1.5 cm. from the original 2-cm. circle of concentration. Different size classes of plantigrades were about equally distributed throughout the zone of dispersion, indicating that all sizes tended to move away from the bright light at about the same rate.

The experiment was repeated with plantigrades ranging in length from 1.0 to 2.4 mm., twenty-five in each of the control and experimental dishes. In twenty minutes all the clams in the lighted dish but one, which remained closed, crawled out of the lighted 2-cm. circle, whereas those in the control remained clustered within the original 2-cm. circle. The degree of dispersion was not so marked in larger plantigrades as in the smaller ones. Hunter (1949) reports that young of *Hiatella* are also negatively phototactic; and Morton (1960) reports that *Lasaea rubra* becomes negatively phototactic at light intensities not much above those of twilight.

These results indicate that when out of sediment, plantigrades of *M. mercenaria* crawl away from light of moderate intensity into areas of dim light, and as they develop siphons and move deeper into the sediment they are less affected by bright light. Whether they respond by moving deeper into the sediment on bright days as at low tide in intertidal areas in nature is not known.

RESPONSE TO FLOW OF WATER. The fact that in some instances plantigrades opened when held in a dish devoid of sediment and started crawling when sea water was forcefully ejected over them from a bulb pipette suggested that they might exhibit a rheotactic response. We tested this during the summer of 1956 in North Carolina. Fifty-five plantigrades ranging in length from 1.0 to 2.4 mm. were placed in a flow trough eight feet long and four inches wide, about two feet downstream from the inflow. Sea water pumped directly from Bogue Sound (salinity 35 $^{0}/oo$, temperature 28°C.) flowed at the rate of 2.5 cm./sec. in the trough and covered the clams to several times their length. Light from windows was arranged so that only twenty-five foot-candles struck the trough at right angles to the flow of the water. In a period of four hours only five clams had moved; these distances ranged from one to four centimeters from the original grouping; two clams crawled upstream, three moved downstream. At least under these conditions, then, no response to flow was detected. This might be anticipated, since in nature clams are generally faced by alternating ebbing and flooding currents rather than continuous unidirectional flows.

SUMMARY OF BEHAVIOR IN LABORATORY. When the pediveliger stage is reached, larvae alternate swimming and crawling, apparently seeking suitable setting surfaces. A negative response to moderate to bright light intensities, possibly combined with a positively geotactic response, may direct them downward onto the more dimly lit bottom. During the byssal plantigrade stage, after the swimming organ is lost, they affix most densely where sediment of fine sand and/or organic detritus lies thinly over solid surfaces. Photonegative and strong thigmotactic responses impel them to remain in contact with the bottom and, as the siphons develop, to burrow into the sediment. Thorson (1950) notes that the ability to postpone metamorphosis and actively seek substrata is widely distributed among marine larval invertebrates.

Byssal Plantigrade Stages in the Field

Factors Affecting Distribution and Density. In general observations on distribution of juveniles and adults of *M. mercenaria* in Great Bay and Little Egg Harbor during the period 1947–51, we often found clams concentrated most densely along the edges of channels and sloping portions of bars, among shells and living oysters, at the base of piling and similar baffles, in muddy sand in sod hollows offshore from eroding marsh banks, and in level bottoms characterized by slight irregularities.

At least the following factors may be hypothesized as instrumental in regulating density and temporal and spatial distribution of this bivalve on the bottom: (1) the rate of development of parental gonads, the time of spawning, and the duration of veliger stage, all affected at least in part by environmental temperatures; (2) the proximity and abundance of spawning parents and volume of spawn and the survival, transport, and degree of dispersion of the veliger stage by water masses from parents to setting sites; (3) the attraction of pediveligers to gradients of turbulence surrounding objects extending from the bottom which offer resistence to tidal flow; (4) the nature of the bottom and the intensity of light at the time of setting; (5) swimming by pediveligers and crawling by byssal plantigrades subsequent to initial settling to the bottom, and movement and concentration of byssal plantigrades affixed to organic fragments and fine grains of sand by swift tidal currents; (6) depredations by predators. The multiplicity of these factors undoubtedly accounts for the unpredictability of time and site of setting and subsequent density and distribution of this mollusk.

Information on behavior of pediveligers and byssal plantigrades in the laboratory and on the ecology of larvae in the field has been presented in earlier sections and sheds light on some of the points listed above. The following paragraphs will report field studies of post-set clams and provide additional information on their behavior, distribution, and density.

In the summer of 1949 between mid-July and the end of August, we made a careful study of the distribution and density of setting of *M. mercenaria* in Lower Little Egg Harbor. The largest veliger swarms were detected in late June and early July (Fig. 25); thereafter very little spawning was noticed. In deep water, sediment samples were collected with the Petersen grab. Ten full grabloads constituted a sample at any station. Samples were dumped onto screens suspended in a metal sluice set across our motor boat and then washed with a stream of sea water from a pump in the boat. In shallow water, samples were taken by hand and washed on hand screens. Mr. Pomeroy collected the samples and provided me with a record of his field observations.

The lengths of plantigrades collected ranged from one to several millimeters. Sets occurred widely though irregularly throughout the bay. Their distribution did not coincide entirely with that of adults, for there were some bottoms with dense populations of young adults in which no plantigrades were found. The maximum concentration, 125 byssal plantigrades per square meter, was located on a shell bar in Thompson Creek (Fig. 14); the next highest, 54 per square meter, was taken in the central region of the bay. Dissoconchs were measured in anticipation of recording growth rate. Size range was extreme, however, and no measurements of any day's collection fell into a normal curve of distribution; the curves assumed bi- or trimodal or irregular form. This irregularity probably reflected the occurrence in time of a series of sets on the same bottom as well as wide limits of size variation of different age classes (as demonstrated in laboratory growth studies). Thus it was not possible to obtain reliable progressive size increments from the data.

The dense set in Thompson Creek provided information on behavior and mortality rate of byssal plantigrades. The set was discovered initially on July 12 on an artificial shell bar in the mouth of a tidal creek tributary to Thompson Creek and near the "Cynthia." A census on July 13 showed that dissoconchs ranged in length from one to four mm. The maximum population density, about 125 clams per square meter, was located on the shallowest portion of the bar, which also held the heaviest covering of oyster shells; density decreased down the sides of the bar, and plantigrades were quite infrequent on the unshelled mud bottom around the bar.

Mr. Pomeroy noticed that plantigrades were found principally in single upturned oyster shells containing mud (mixture of organic detritus and fine sand and silt). This mixture was flushed gently from the shells into a screen with a bulb pipette; flushing uncovered the plantigrades, which remained affixed to the shells, even to sites covered by more than a centimenter of mud. Plantigrades were not visible on the surface of the mud or on clean shell, apparently having selected surfaces covered by sediment. Mud under and around the shells contained but a fraction of the number found in the shells. These observations confirm those made in the laboratory and suggest that in the field, byssal plantigrades seek out available solid surfaces on which to anchor, surfaces which are coated by sufficient loose material to permit them to burrow as soon as their morphology permits. These ecologic requirements may be satisfied by the presence around hard surfaces of a variety of mixtures of fine sedimentary grains. Coarse gravel or shell or organic mud alone do not seem to constitute as desirable setting sites. In firm sandy or sandy mud bottoms devoid of hard substrates, as in Lower Little Egg Harbor, plantigrades make multiple attachment to several grains of sand at a time. A dense set of *M. mercenaria* on an intertidal bar in Shark River channel, some 40 miles northward along the New Jersey coast, made possible observation of the position of byssal plantigrades about 3.5 mm. long in clean fine sand. The activity of dissoconchs was observed as incoming sea water rose over the bar to a depth of a half-inch. Plantigrades were buried to about one-half their height, and they clung to surrounding sand grains by means of thin, branching byssi, as described by Belding (1912) for young clams in Massachusetts, their short definitive siphons and siphonal sleeves fully extended as they actively pumped water. The role of clean, unstable sand and larger particles in setting, concentration, and survival of plantigrades in channels and inlets of swift tidal flow has already been discussed (Carriker, 1959; Turner and George, 1955); in general, byssal plantigrades are well adapted for life in these shifting sediments.

After several weeks we noted that plantigrades on the Thompson Creek shell bar were no longer as closely associated with shell surfaces. Examination of upturned oyster shells, as in the preceding survey, revealed the presence of only a few plantigrades, whereas screening of sediment around the shells revealed many more. Two explanations suggest themselves: either dissoconchs, on reaching a certain size or age, crawl from the shell into the surrounding sediment, or those in cupped shells are largely removed by predators, whereas those in the sediment around the shells escape enemies in greater measure. Possibly both factors operate, their degree of importance correlated with the type of bottom materials and the number and kinds of predators present.

By July 30, some two weeks after the initial survey of the artificial shell bar, mortality of plantigrades on the bar approximated 50 per cent. Other areas in the bay where successive sampling was carried out demonstrated a similar trend in mortality.

Since the plantigrade population on the shell bar was already some weeks past the setting time when first discovered, its density, because of inroads of predators, undoubtedly represented but a fraction of the original one. An effort was made to determine the original setting concentration on the basis of living dissoconchs and fresh shell fragments. Bottom material on the bar was screened through nested screens of 1 and 0.5 mm. pore size. Living plantigrades and fresh empty valves and valve fragments were removed and recorded. After several weeks of this study, the initial population density (that at July 13) was compared with those estimated from subsequent analyses. The conclusion was that even if every single valve and fragment were counted as an individual, the figure seldom exceeded 50 per cent of the density of the population at discovery. Furthermore, it was soon apparent that the quantity of empty valves and fragments recovered varied widely with nature and location of bottom, since delicate material of this kind is subject to removal by tidal currents and to rapid destruction by abrasion induced by waves and currents. Thus collection and sorting of dead shell material gave some information on the nature of predators, but proved unreliable for determining the density of the clam population at time of setting.

As a sequel to study of the distribution of byssal plantigrades in Thompson Creek, it is worth reporting a detailed study made by the writer in 1948 of the distribution of a dense population of hard clams in a system of old baffles on Edge Cove Bar. Local clammers said that they had not harvested Edge Cove, and our preliminary sampling disclosed a population represented by several year classes, ranging in length from a few millimeters to 8.4 centimeters. Although the population on the bar was relatively undisturbed by man, it was subject to predation by at least the following animals common to the area: *Busycon canaliculatum, Urosalpinx cinerea, Callinectes sapidus,* and xanthid mud crabs.

Edge Cove Bar runs eastward from the shore of Edge Cove (Fig. 34) about 200 feet; it is 40 feet wide, about a foot above the level of the cove and it is composed of a mixture of coarse and fine sand, shell, and mud overlying the firm marsh mud with its entanglement of partly decayed *Spartina* roots. Many years ago an extensive system of vertical and horizontal piling was installed for a dock and buildings, and the bottom was hardened by addition of sand and shell (T. C. Nelson, personal communication). At the time of this study many of the old timbers were still on the bar and afforded several combinations of baffles, boards, and posts ranging in height from the level of the bar to five feet with diameter up to eight inches. Most conspicuous were two rows of piling running the full length of the bar (Fig. 37); short rows extended at right angles from these, and single piles and clusters of piling were scattered over the bar. The bar sloped gradually from the beach to a depth at mean low water of approximately 30 inches at the outer end; during extreme low tides coinciding with strong westerly winds, the inner third of the bar was exposed. Tidal currents moved across the bar into tidal creeks at right angles to the principal rows of baffles. Current velocity, as measured through the cycle of an average tide, attained a maximum velocity of 10 cm./sec. over the outer end of the bar, and about 8 cm./sec. midway out the bar. Rainfall, tidal amplitude, salinity, and water temperature for the Edge Cove area are summarized in Figure 15.

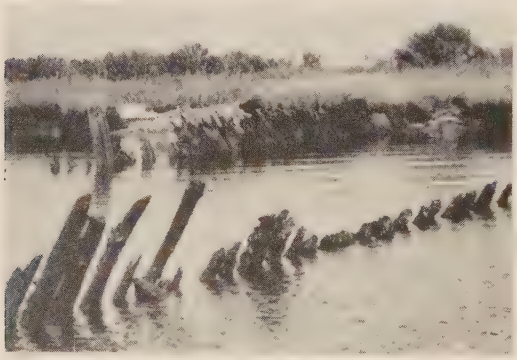


FIG. 37. Photograph of major rows of baffles on Edge Cove Bar, Little Egg Harbor, N. J., at mean tide level (compare with Figure 15: 1948).

A census of the bar was made in the following way. During periods of low, calm water, sediment on the bar was first scraped from quadrats 1 × 3 feet at a time and washed on a screen of 1-mm. pore size. This operation collected small clams. The remainder of the quadrat was then searched to a depth of some six inches for larger individuals. Quadrats were chosen to include the range of types of bottom and baffles present. A total of 372 square feet of bottom was examined, and 1,178 clams were collected, distributed in the following size classes:

Length Range, mm.	*Number*
5–24	132
25–37	74
38–50	223
51–63	432
64–75	235
76–84	82

These figures suggest that setting of *M. mercenaria* over the previous eight or so years (age of the oldest clams approximated from number of annual growth rings) occurred rather consistently, though they cannot give much information on relative density at time of setting, since the variables of setting intensity and predation pressure are not necessarily correlated.

A census of the bar provided an average density of about three clams per square foot of bottom—a misleading figure, since density varied from 0 to 50 clams per square foot, dependent on presence or absence of baffles, depth of water, and nature and slope of the bottom. Maximum concentrations occurred in an area 100 to 200 feet from the shore in a minimum depth of water at mean low tide of about one foot, and always in sediment around baffles of all types: round piling, slats, stones, sunken logs, and shell. The highest density encountered—150 clams per three square feet—was found at a distance of 184 feet from the shore in two feet of water (mean low tide) around a post seven inches in diameter and three feet high, surrounded by a cluster of shorter, smaller stakes, stones, and shell in a mixture of mud and coarse sand. In comparable quadrats ten feet away but lacking shells and piling, no more than four clams were present. The type of piling, whether slats or round, did not appear to affect concentration, though more clams were found around higher baffles. Bottom littered with bivalve shells always contained more clams than similar bottom without shell, a phenomenon also observed on the Thompson Creek shell bar. Sand or a mixture of mud and sand or pliable mud generally contained more clams than comparable bottom consisting of hard marsh sod. Clams were also more dense where the nature of the bottom changed abruptly from hard mud to sand than in either the mud or sand, and more numerous along the marginal slopes than on the plateau of the bar.

The following points may be induced from the study of distribution of *M. mercenaria* on Edge Cove Bar: (1) Objects in the water, acting as baffles to currents, create current velocity and turbulence differentials which may stimulate pediveligers to set around the baffles in greater abundance than on bottom without such baffles. Since, however, the location of adult clams does not necessarily delimit the setting area nor their number indicate setting intensity, the survey provides only circumstantial support of this point. (2) Behavior of byssal plantigrades in the laboratory and on the Thompson Creek shell bar suggests that they tend to move into shaded microhabitats filled with shallow sediment, such as cupped shells, crevices in piling, depressions among sessile occupants of hard surfaces, and boundaries between hard surfaces and loose sediment. Thus they may crawl or swim into the vicinity of such baffles secondarily after settling to the bottom, in addition to those which set originally about the baffles in response to gradients in the turbulence of the water. Baggerman (1953) has shown that young cockles (*Cardium edule*) are transported by water masses long after metamorphosis and until they reach a length of 1.8 to 2 mm. (3) Baffle areas provide microhabitats which provide pediveligers and byssal plantigrades some protection from predators. Consequently, even if setting were uniform over the whole general area, survival would be greater in the immediate vicinity of the baffles. Probably all of these factors are functioning collectively, though in varying degrees in different environments. For example, attraction of pediveligers to gradients of turbulence may be maximal in areas of swift tidal currents, while in regions of more sluggish circulation secondary movement of young clams to the protective baffle site may play a more important role in concentration there. And in areas of unstable sediments and swift tidal currents rate of predation is relatively low as compared with that in more quiet areas (Carriker 1959).

Belding (1912) noticed that sets of *M. mercenaria* often occurred in eddies or on the sides of a swift current. Orton (1937), in a study of the intensity and distribution of spatfalls of *Cardium edule* in Morecambe Bay, notes that these bivalves "become concentrated and precipitate out of the plankton in localities where slack and eddy waters occur." The possible role of the action of water motion in concentrating setting pediveligers is discussed briefly by Turner (1953), and as he points out, since we do not yet know the response of pediveligers to gradients of turbulence under controlled conditions in the laboratory, we are not in a position to do more than hypothesize on the role of turbulence in vertical distribution and setting of these larvae.

EXPERIMENTAL STUDY OF SETTING IN THE FIELD. Because byssal plantigrades soon mingle with surface grains of sediment after metamorphosis, it is difficult to study rate and intensity of setting, growth rate, and survival in the field. During the five summers in Great Bay and Little Egg Harbor we developed a setting indicator, based on Thorson's (1946) "bottle-collector" for gathering newly set sessile invertebrates, by means of which it was possible to make a beginning in such studies.

The clam-setting indicator was evolved to take advantage of those characteristics in the setting behavior of pediveligers which would stimulate them to affix in the indicators: (a) possible attraction to gradients of turbulence about objects in water, (b) preference during daylight for microhabitats in subdued light, and (c) preference for contact with shallow layers of fine sediment over hard surfaces. The device protects plantigrades from outside predators without deleteriously impeding flow of tidal water, food, and oxygen over them, so that they feed and grow normally in it. The indicator may be removed from the water with a minimum of disturbance and the plantigrades within it studied alive in the laboratory and returned in the indicator to the water. The device further makes possible relatively easy detection and manipulation of young plantigrades in a minimum of fine sediment.

Setting indicators were constructed from the upper third of narrow-mouthed, one-gallon glass bottles six inches in diameter across the inverted large end (Figs. 38, 39). A one-hole rubber stopper with a five-inch paraffined, galvanized, large-headed nail in it was inserted in the neck of each bottle top. A piece of wooden doweling eight inches long and seven-eighths inch in diameter fit snugly into the neck of the bottle top, and plastic screening (pore size approximately 1 mm.) was wrapped over the doweling and bottle top and secured at the neck with plastic twine. Plastic screen and twine were unaffected by exposure to sea water over periods of several months.

Indicators were supported on a frame which made it possible to place them anywhere in the shallower portions of Lower Little Egg Harbor. The frame consisted of (a) a long, stout, cedar guide pole about three or four inches in diameter

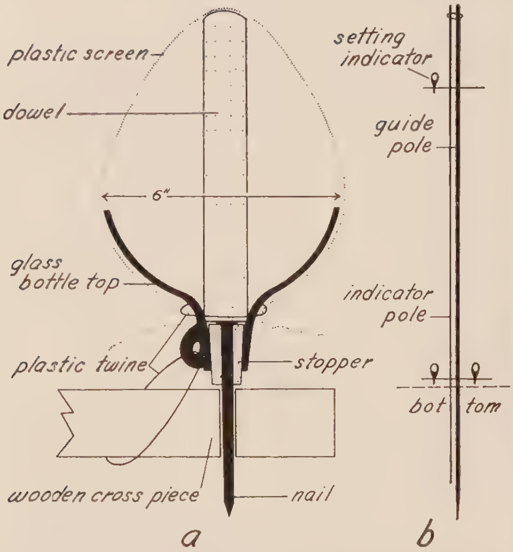


FIG. 38. a. Drawing of hard-clam setting indicator. b. Drawing of support for hard-clam setting indicator.

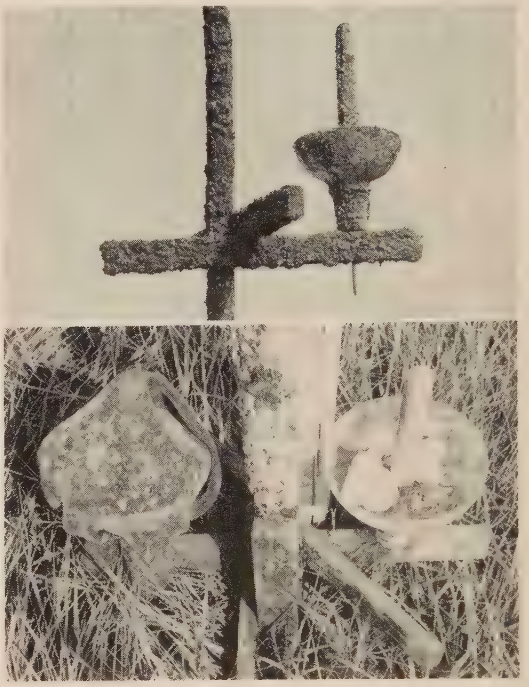


FIG. 39. Photograph of (a) (top) an uncovered setting indicator in position on the top rung of an indicator support after exposure to fouling organisms; (b) (bottom) two indicators on bottom rung of support; the one at left covered by screen, the one at right uncovered and containing a variety of substrates used in early experiments and later found unnecessary.

at the slender end which was driven stout end first into the bottom to a sufficient depth (some three feet in soft bottom) to provide secure anchorage for the indicators and temporary moorage for a small boat and be visible above water at high tide; and (b) a long, light, slender indicator pole, likewise pointed at the stout end, with two sets of cross pieces nailed to it, one set located near the lower end of the pole and intended to rest on the bottom, and the second set so placed as to remain at least a foot or two below the surface of the water at low tide (Fig. 38b). Indicators were slipped into holes drilled on the outer ends of the cross pieces and held in position by plastic twine looped around the cross pieces and handles of the bottle tops. In operation the indicator pole was guided down the guide pole to, and pressed a short distance into, the bottom. The two poles were then fastened together at the top with heavy twine. When indicators were inspected, the indicator pole was brought carefully into the boat in a vertical position, and indicators were untied and lifted from their supporting cross pieces.

Bottle tops were selected for indicators because (1) glass provides a hard, easily cleaned, internal surface, (2) the tops can be lifted from the bay without disturbing the contents unduly, and (3) plantigrades and sediment may readily be dislodged (with a thin-edged rubber spatula or test-tube brush) and rinsed (with a large bulb pipette) into beakers for analysis in the laboratory. Some of the hard plastic bottles now on the market may serve as well as the glass and contribute the advantage of unbreakability. After screening and counting, sediment and plantigrades may be returned to bottle tops and replaced in the bay, or plantigrades may be examined directly in the bottle top under a microscope after sediment has settled and water has cleared. Plantigrades affix to glass within the bottle top principally along the advancing edge of accumulating sediment and may be located there after most of the sea water in the bottle top has been siphoned out.

The cone of plastic screen over the bottle top, which excludes predators, reduces light intensity and creates a differential in rate of water flow over the bottle top, was cleaned of fouling organisms by brushing. Some screens which had been painted with commercial copper paint to reduce fouling remained free of most fouling organisms for at least two months of submergence but may have reduced the quantity of clams setting in the indicators. Bottle tops

Table XIII

Schedule of placement and examination of clam setting indicators and density of set per bottle top at Station 4 in Lower Little Egg Harbor.

Location of top and type of screen	DATES OF PLACEMENT AND EXAMINATION OF TOPS							
	July							August
	3	7	11	17	21	27	31	28
(1) Bottom, unpainted.......	Set	0	0	0	0	—	0	discontinued
(2) Bottom, unpainted.......	—	—	—	—	—	Set	1	202
(3) Bottom, Cu-painted......	Set	0	0	1	0	—	0	125
(4) Surface, unpainted.......	—	—	—	—	—	Set	1	140

were examined in the field during periods of relatively quiet water, since rough water caused the boat to pitch and roll, spilling the contents of the indicators.

A field test of the fully developed clam-setting indicator was first made during the summer of 1951 at Station 4 in Lower Little Egg Harbor. Four indicators were placed on one indicator pole as follows: three (one with a copper-painted screen and two with unpainted screens) near the bottom with the rim of each bottle top about six inches above the surface of the bottom, and one (with unpainted screen) four and a half feet above the bottom in water seven feet deep at mean low water. The schedule of setting and examination of the indicators is presented in Table XIII.

The following procedure was employed in examining effectiveness of bottle tops as setting indicators. Sediment and occupants were brushed and rinsed into glass dishes and transported to the laboratory. Plantigrades remained alive for at least four days in these dishes, even though they were thoroughly mixed in sediment at the start and had to crawl to the surface through some two centemeters of organic mud. In the laboratory sediment was flushed in small quantities through two nested stainless steel screens, No. 60 (pore size 260–340 μ) and No. 100 (165–210 μ). Residue from each screen was then rinsed into a large, deeply concave dish (bottom portion of a Kjeldahl flask), where it was swirled circularly by the force of water ejected from a large bulb pipette. Plantigrades, being relatively heavy, remained on the bottom, which permitted floating materials to be drawn off. Mechanical vibration caused by the handling of containers tended to keep dissoconchs closed; however, as a precaution against the possibility that pediveligers might start swimming and be drawn off with floating residues, brackish water instead of sea water was employed in screening and swirling. Sediment and animals remaining after swirling and cleaning were rinsed into a shallow watch crystal about four inches in diameter and concentrated in the center of the dish by further swirling. Materials held on the No. 100 screen were examined under a magnification of 25X, and those on the No. 60 screen under 15X magnification. A dissecting needle bent slightly and filed flat at the tip on opposing sides facilitated sorting and movement of sediment under the microscope. Most dissoconchs, possessing a density slightly less than that of sand, were concentrated at the outer edge of swirled materials. Where excessively large quantities of sediment collected in bottle tops, aliquot fractions were examined.

The relation of the density of set obtained in indicators and the density and temporal distribution of larvae in the bay may be seen by comparison of Table XIII and Figure 27. Although dense swarms of larvae appeared during the period July 10–13, no late stages of these larvae were recovered in plankton samples, and only negligible setting took place: one pediveliger 200 μ in length was taken in bottle top (3) on July 17. Since clean bottle tops (1) and (3) had been placed in the bay only six days earlier, there is a possibility that insufficient sediment had accumulated in them by the time pediveligers came by. This suggests that bottle tops be inoculated with a small quantity of fine-screened sediment before placement in the water. In spite of the fact that large swarms of clam veligers present in the water on July 23–25 remained in the water in small numbers through the late umbone stages, setting in bottle tops was still negligible (see July 31 examination, Table XIII). Two explanations are suggested: either setting occurred in other parts of the bay, or there was insufficient sediment in the bottle tops to attract those pediveligers which passed by.

The principal set of the season in bottle tops was found on August 28 (Table XIII) after the indicators had been unattended for four weeks. At this time the indicators on the bottom were filled to within three-fourths inch and the one near the surface to within two inches of the rim with fine sediment which entered in suspension and settled as the flow of water decelerated in the bowl of the indicator. The maximum density was found in the bottom indicator with unpainted screen (202 plantigrades), intermediate density in the indicator near the surface (140), an minimum density in the bottom indicator with the copper-painted screen (125). These data suggest that pediveligers may be distributed throughout the vertical column of water and that there is setting at all depths, with no clear tendency for greater setting at any depth. Furthermore, copper paint may tend to repel pediveligers.

The area of the open end of each bottle top was 28 square inches, or 0.2 square foot. Thus (though the optimal setting surface within each bottle top, the shallow shore around the accumulating pool of sediment, was many times less than the area of the opening of the top), the density of set ranged from 625 to 1,010 plantigrades per square foot of bottle top. Since concentrations of this magnitude were never found in natural bottoms in the area, it may be inferred that indicators functioned in at least two ways in compounding such densities: (a) by excluding macroscopic predators and to a large degree eliminating predatory loss of plantigrades, and (b) by concentrating pediveligers which were stimulated to enter and to remain, attracted by conditions in the indicator. It is doubtful that pediveligers were trapped in the sense that they could not leave after entering the device, since they should have been able to swim out as readily as in, and after loss of velum to creep out through the screen, though once valves exceeded dimension of pores in the screen (approximately 1 sq. mm.), plantigrades were caged.

The size of plantigrades taken in indicators fell in two major length classes: (a) 3 individuals 900–1,400 μ, which on the basis of rate of growth of plantigrades in our laboratory, came from the spawning of July 30 (Fig. 27); and 464 individuals 208–340 μ, which came from the spawnings of August 9 and 18. Late-stage umboned veliger larvae were recovered from the water after all these spawnings, and in more than usual abundance after the August spawnings. Thus intensity of set in the bottle tops was roughly proportional to abundance of late-stage veligers in the plankton.

The distribution of plantigrades in these indicators and in earlier, less effective models in which a variety of setting surface was provided demonstrated that the preponderance of setting occurred on hard surfaces overlaid by shallow layers of sediment. This confirmed observations made in the laboratory and suggested elimination of "cultch" of any sort from the bottle tops (Fig. 39b, right), thus greatly simplifying the construction and use of indicators.

Bottle tops were successful in accumulating other invertebrates. Barnacles, serpulid polychaetes, xanthid mud crabs, and the bivalves *Teredo, Mulinia, Modiolus, Tellina,* and *Tagellus* were commonest. Hardiest of the bivalves were *M. mercenaria,* which remained alive longest in dishes in which the content of indicators in some instances was stored for several days. As many as four or five young mud crabs up to six mm. in width were found in all indicators on August 28. These entered as plankters and grew, and then could not escape. The age they commence preying on young bivalves, or whether they destroyed any plantigrades in the indicators, is unknown. The large concentration of dissoconchs in bottle tops would suggest that little if any predation did occur. Studies showing at what size or age different species of crabs begin attacking young hard clams would be helpful in establishing a time interval between placement and examination of indicators in order to eliminate predation by young crabs.

Clam-setting indicators were employed in Home Pond (Carriker, 1959), but pediveligers were not present in sufficient quantities at the time to produce more than an occasional plantigrade in the indicators.

IV ENEMIES

Hard clams of all ages are hardy animals tolerant of a wide range of physical environmental conditions. Of all the stages in the life cycle, veligers are considered the most sensitive, and yet these are successful within a broad range of many factors. Davis (1958) reared shelled veligers to metamorphosis in constant salinities ranging from 17.5 to 35 ⁰/oo in Connecticut; in North Carolina the maximum salinity of the water (which did not drop below 31 ⁰/oo) in our cultures was 36 ⁰/oo. Loosanoff et al. (1951) and Loosanoff (1959) in Connecticut grew larvae to setting at constant temperatures ranging from 18° to 30°C.; and in New Jersey the temperature of the water in our larval cultures, fluctuating with air temperatures, ranged from 13° to 30°C.; in North Carolina maximum temperatures reached 31°C. Since post-set stages of hard clams in the field occur in sediment types ranging from clean sand to organic detritus, in bottoms varying from those beneath sluggish wind-driven circulation to inlets with extremely swift tidal currents, and in various degrees of exposure in intertidal zones, it may be concluded that pediveligers and byssal plantigrades likewise withstand at least this spectrum of conditions.

However, *M. mercenaria,* particularly in the early stages, is attacked by a surprisingly long list of organisms. In this section we report our observations, and those of other investigators, of enemies of young stages of this bivalve.

PLANKTON FEEDERS. Thorson (1946), from an exhaustive study of the planktonic larvae of Danish bottom marine invertebrates, concludes that the striking loss of these animals before and during setting is due only in small measure to lack of fertilization of eggs, starvation, extremes of environmental factors, or unsuitable substrates, since probably all are able to postpone metamorphosis for some days or weeks, providing time for selection of suitable setting surfaces. Major losses, he believes, are probably due to a large number of planktonic, pelagic, and benthic animals which feed in part or entirely on planktonic larvae (Thorson, 1950).

We did not have opportunity to examine the stomachs of marine animals associated with *M. mercenaria* in Little Egg Harbor. But on the basis of the observations of others as summarized by Thorson (1946), and animals present in Little Egg Harbor, it is reasonable to suspect at least the following as predators of one or more of the planktonic and newly set stages of *M. mercenaria* in Little Egg Harbor: *Noctiluca, Aurelia, Diadumene, Mnemiopsis,* decapod zoea, *Balanus, Chthamalus, Crassostrea, Mercenaria, Mytilus, Modiolus,* and *Brevoortia.* In this connection Belding (1912) notes that "all manner of fish, crustacean and molluscan life feed on the larvae, even the mother quahaug sucking down her own offspring." This array of predators could well produce the high mortality of hard-clam veligers we observed in Little Egg Harbor. Furthermore, low concentration of veligers near the bottom may be explained in part, perhaps, by depletion of larvae by filter-feeding predators there, though that that is not the whole explanation is indicated by the vertical movements of the larvae. As Thorson points out, the volume of water which these bottom-dwelling predatory forms filter per day must be a sizeable fraction of the total volume of water present. Rice and Smith (1958) have determined that for *M. mercenaria* alone in suspensions of diatoms the average filtering rates range from 3 to 6 liters per hour, and in suspension of green algae, as high as 2 liters per hour.

FUNGI. *Sirolpidium* sp., first described by Davies et al. (1954) in laboratory-reared veligers and identified by us in our larval cultures on Gardiners Island, on occasion reached epidemic proportions. As described by Davis, the majority of the infected larvae stopped growing and died soon after infection. We did not encounter the fungus in laboratory cultures in North Carolina.

PROTOZOA. Loosanoff (1959) reports that the large heterotrich ciliate *Condylostoma* sp. ingests hard-clam veligers when present with them in his laboratory cultures, a single ciliate consuming as many as six larvae. We did not find this organism in our cultures.

DECAPOD CRUSTACEA. As soon as the high mortality of byssal plantigrades was noted on the Thompson Creek shell bar, we made a search for their major predators. Suspected predators were isolated, each species with a group of plantigrades, in small screen cages suspended in the water from the "Cynthia."

Of the xanthid mud crabs—*Eurypanopeus, Neopanope, Panopeus,* and *Rhithropanopeus*—in the area, *Rhithropanopeus* was most common in the slightly brackish waters of the creeks and coves along the western shores of Little Egg Harbor, and was therefore used in the experimental cages. In some bottoms the density of mud crabs exceeded that of byssal plantigrades. Crabs were divided into two size groups, and each was given hard clams ranging in length from two to about nine mm. in length. Crabs having a carapace width of 1 cm. crushed dissoconchs less than 3 mm. long; crabs 2 cm. wide crushed dissoconchs 6 mm. long. These decapods, and especially the larger size, were voracious: one in a cage with fifteen clams consumed thirteen in three days. Flesh was obtained by completely crushing the valves with the chelipeds, leaving a residue of clean irregular shell fragments.

Depredation of juvenile *M. mercenaria* by Xanthidae, *Callinectes sapidus,* and *Carcinides maenas* has been reported by several authors (reviewed by Carriker, 1959). Although predation of byssal plantigrades by young blue and green crabs has not been recorded, it is likely that much does occur, and the possibility merits study.

MEROSTOMATA. No large numbers of *Limulus polyphemus* were present in any of our study areas, but T. C. Nelson (personal communication) reported that on the intertidal flats of Cape May, New Jersey, where the horseshoe crab was abundant, densities of newly set *Mya* running to a maximum of 9,000 per square foot were completely destroyed by decapod crabs and horseshoe crabs in a few weeks. Shuster (1950) writes that small specimens of *Limulus* feed on minute organisms that live in the surface sediment, and that as they grow they feed on larger prey; the diet of adults consists chiefly of marine worms and several species of bivalves. This animal, then, may be considered a serious potential predator of at least younger stages of *M. mercenaria.*

MURICID GASTROPODA. Examination of empty hard-clam byssal plantigrade valves collected in the field in Little Egg Harbor disclosed the presence of many small relatively straight-walled holes in the shells. The only boring gastropods known to exist in the area were *Urosalpinx cinerea* and *Eupleura caudata.* Young snails isolated in experimental cages with byssal plantigrades bored holes similar to those encountered in empty valves in the field. Location of the holes in valves varied widely, and not infrequently snails penetrated between the valves, leaving a hardly visible crescentic nick on each valve.

Subsequent laboratory studies (Carriker, 1957) in North Carolina demonstrated clearly the voracity of newly hatched *Urosalpinx cinerea* and the degree to which young dissoconchs of *M. mercenaria* are drilled and consumed. These young conchs exhibit a pronounced positive chemotactic response to the external metabolities of young clams, and readily locate them. A snail 1.5 mm. in height perforated a clam 0.6 mm. in length in 45 minutes and rasped out the flesh in an equal time. Predation rates varied from one to nineteen young clams drilled and consumed per conch per day. (However, it should be emphasized that in the field other species of bivalve prey would constitute buffer-food species which would tend to reduce the rate of predation of clams.) Young *Urosalpinx* can crawl through superficial layers of sediment, thus easily reaching those young clams which have burrowed shallowly after formation of definitive siphons. Although veliger and protoconch stages in these snails are passed in an egg case, young conchs may be widely distributed by crawling onto debris and floating on it in tidal circulation (Carriker, 1957).

NATICID GASTROPODA. Two common species of this group of boring snails—*Polinices duplicatus* and *Polinices heros*—are encountered in habitats in association with hard-clam populations. In Little Egg Harbor the former were abundant on the bay side of the barrier beaches. The perforation drilled by these species differs characteristically from that by muricids listed above in being distinctly and broadly bevelled. Hanks (1960) reports that recently metamorphosed *Polinices* are able to bore into small bivalve prey. H. N. Gibbs (personal communication) observed moon snails 2 mm. in diameter, and we saw specimens 4 mm. in diameter, drilling young bivalves.

The high rate of predation of burrowing bivalves by adult naticids has been reported several times (see review by Sawyer, 1950; Carriker, 1951; Ansell, 1960; Hanks, 1960); buried prey find no protection in sediment, since moon snails themselves are such facile burrowers. Only one published report is available on predation by young moon snails. Sawyer (1950), utilizing *P. duplicatus* ranging in diameter from 9 to 12 mm. in laboratory experiments in Massachusetts, learned that at a water temperature of 21°C. snails drilled and consumed 0.67 individual of *Mya arenaria* per day. Increase in weight of the snails during a thirty-day feeding period approximated one-twentieth of the weight of the clams consumed during that time.

A high rate of predation combined with a pelagic larval stage and an unusual method for pelagic distribution of young conchs (Shuster, 1951) make young *P. duplicatus* formidable enemies of young bivalves. During the first week in August, 1951, Shuster observed young snails 4.0 to 9.4 mm. in diameter concentrated on sand bars 400 yards offshore on the New Jersey Cape May intertidal flats. Three weeks later hundreds of individauls of the same population, now ranging in diameter from 6.4 to 16.5 mm., were seen with foot fully expanded floating and drifting across the tidal flats on the shallow incoming tide. As water flooded the flats, snails lifted the propodium, curled the sides of the foot downward and inward, and rolled over on their sides. They floated readily in this position with a large sheet of mucus passing from the extended foot.

OTHER GASTROPODA. The capacity of adult *Busycon carica* and *B. canaliculatum*, both common associates of *M. mercenaria,* to penetrate hard clams by mechanical chipping has been described, and a preliminary estimate of the rate of predation in New Jersey has been recorded (Carriker, 1951). Probably other species of whelks penetrate tightly closing bivalves in a similar manner, though this should be verified. The size at which young whelks first attack young hard clams has not been determined, but it is probably soon after emergence of the protoconch from the egg case.

Young of several species of browsing snails—like *Nassarius obsoletus,* which occur in such abundance in hard-clam setting areas—though not predators (Jenner 1956) may inadvertently consume early byssal plantigrades with detritus and microscopic organisms as they rasp over the surface sediments with the radula. Preliminary observations by us, and independently by Turner and George (1955), indicate that the mud snail does not consume clams 0.5 mm. or more in length. However, the study of accidental consumption of newly set byssal plantigrades by browsing mud snails may show a different picture and should be studied.

ECHINODERMATA. Sea stars like *Asterias forbesi* and *A. vulgaris* may occur in conspicuous abundance (Burkenroad 1957) in areas where *M. mercenaria* is likewise found, and the damage which these adult asteroids inflict on macroscopic epifaunal bivalves is well known. Whether recently metamorphosed sea stars attack byssal plantigrades of hard clams before they burrow beneath the surface of the sediment has not been investigated. It is likely that they do.

TUNICATA. On Gardiners Island larvae of *Molgula manhattensis* entered in running sea water and settled in trays in the laboratory. As the tunicates increased in size the valves of hard-clam byssal plantigrades became fastened to their tunics. In one instance we found six ascidians with some 150 plantigrades, of which about 5 per cent were dead, stuck fast to and partly overgrown by the tunic. It would appear that hard clams were attracted to the hard surface provided by the tunicates, attached by means of the byssus, and then became embedded in the tunic as it enlarged. Whether deaths were brought about by this is not known. Sea squirts of this species settling in trays of young hard clams in the field collected plantigrades about them in a similar way. Ryder (1889) reported the attachment by the byssus of large concentrations of *Mya arenaria* to the tunics of *M. manhattensis* in the field and did not notice adhesion of the valves to the tunic. Polychaete larvae (*Polydora* sp.) also entered our laboratory trays, and as they grew constructed tubes of detritus which did not, however, affect the young clams.

OSTEICHTHYES. Bigelow and Schroeder (1953) report that the puffer *Sphaeroides maculatus* (an inshore, shallow-water summer fish found along the Atlantic coast in abundance) includes small mollusks in its diet. Young fry 7 to 10 mm. in length collected near Woods Hole contained "molluscan larvae" (presumably early plantigrades) in the stomach. T. C. Nelson (personal communication) has observed puffers in shallow water in the field, inflated with water and upended over the bottom, washing young clams out of the sediment with streams of water jetted from the mouth. In Little Egg Harbor we caged a small puffer with young hard clams in an attempt to study this behavior, but the fish did not feed, perhaps because of confinement in the cage. Further observations are indicated.

ANSERIFORMES. Some ducks and geese are reported to consume small marine bivalves (Martin and Uhler, 1939). These birds which congregated on ponds on Gardiners Island during the winter thoroughly worked over the shallow bottom with feet and bills, leaving it pockmarked by craterlike depressions two to six inches deep and up to a foot in diameter (Carriker, 1959). Determining the quantity of young hard clams consumed in this way was not possible but it is probable that many were sieved from sediment by the birds.

V DISCUSSION AND CONCLUSIONS

Mercenaria mercenaria is a typically American species found principally along the eastern seaboard of North America. Its habitat is the more saline coastal embayments and estuaries; only occasionally does it appear to survive in the open ocean, and then it is found in the close vicinity of inlets.

Possessing a planktonic larval stage, the hard clam is confronted simultaneously with the advantage of dispersal of its young to widely available suitable substrata in embayments and estuaries and with the potential danger of transport out to sea to unsuitable habitats. To what degree the latter occurs is known only in a general way and is undoubtedly dependent upon the specific circulation patterns of each coastal body of water in which the clam resides.

This paper presents information on the role played by functional morphology, behavior, and autecology in fitting early stages of *M. mercenaria* to remain and survive within the complex gradients characteristic of coastal habitats.

In the laboratory trochophores and earliest straight-hinged veligers concentrate noticeably at the surface of culture jars, and presumably the same occurs in nature, though to date the opportunity to observe this has not occurred. As soon as the straight-hinged veliger acquires valves, its specific gravity considerably exceeds that of sea water, so that the larva sinks bottomward as the velum is withdrawn. So far as is known, velar activity persists throughout the planktonic life of the veliger, the velum increasing in size and effectiveness as the veliger increases in size and weight and approaches the pediveliger stage. Though the larva cannot prevent horizontal dispersal, it does actively seek and maintain a vertical position in the water off the bottom and away from bottom-dwelling predators. The veliger constantly faces extinction by pelagic and nektonic filter-feeding animals in the water, but enemies on the bottom are generally more abundant. Even during hours of darkness, when veligers assume a broader vertical distribution and some are taken near the bottom, the zone of maximum larval density occurs in mid strata. Whether the scarcity of veligers near the bottom reflects predation by bottom-dwelling organisms or whether (more likely) the larvae have evolved an as yet undescribed behavioral response that tends to keep them swimming off the bottom—or both—is not known. The significance in terms of survival value of such a response does not require amplification. Further, it is conceivable that some of the diurnal differences in vertical distribtuion of hard-clam veligers may reflect those of food organisms, veligers migrating to zones of maximum concentration of food organisms as they feed. These points have not been demonstrated and should be investigated.

The tendency of adult hard clams to spawn during neap tides and close to ebb slack water in Little Egg Harbor favors retention of the larvae in the bay. During neap tidal periods minimum exchange of water in the bay takes place with that in the ocean, thereby reducing loss of larvae to sea by exchange. Larvae resulting from spawnings at ebb slack tide are transported up the bay during the subsequent flooding tide rather than down the bay toward the inlet; this favors especially those larvae spawned within the horizontal length of a tidal excursion from the inlet.

A short veliger stage, a minimum of eight days in both the laboratory and the field, also confers survival value, enhancing the chance for metamorphosis to occur within the bay before exchange and flushing transport veligers into the ocean. Veligers which appear in the bay coincident with periods of minimal precipitation are further favored in that they face less danger of transport to sea than those confronted with high flushing rates resulting from heavy precipitation. The degree, if any, to which precipitation influences the time of spawning has not been established.

Nor has it yet been determined whether veligers of hard clams, like those of oysters, exhibit differential vertical distribution in the course of veliger development which results in transport of older stages in the long axis of the estuary by nontidal water movements. Distribution of adult hard clams up the Great Bay estuary does suggest that some such mechanism may operate there.

It is probable, though this requires verification, that *M. mercenaria* upon assumption of the late pediveliger stage becomes photonegative, geopositive, and attracted to substrates.

Once the post-pelagic stage has established itself in the bottom, the hard clam moves only short horizontal distances (Chestnut, 1952). For the remainder of its life it is bounded by a narrow substratal horizon and the water mass of a tidal excursion. But early bottom-dwelling hard clams are benefited by two successive stages which provide the animal considerable freedom in selecting a definitive habitat. The first, the pediveliger stage, moves by alternation of crawling and swimming with tidal water masses over large areas of bottom within the tidal excursion. Results of investigations of other invertebrate planktonic larvae would suggest that newly settled hard-clam larvae will not affix by means of the byssus within its area of sampling until suitable bottom is found; and in the event that such substrate is not immediately encountered, the larva may possibly postpone metamorphosis and loss of the velum for an extended period (Thorson, 1950). It is not known for *M. mercenaria* how long metamorphosis may be postponed, or, indeed, to what degree the observed behavior of alternation of crawling and swimming is an indication of "searching." Circumstantial observations suggest that this is so, but further studies should be made to clarify this point. The second phase which provides the larva freedom of choice, though to a much more geographically limited degree, is the byssal stage, in which the animal alternates byssal fixation with crawling on a still highly effective motile foot. Thus in the presence of adverse localized environmental factors the clam can move a short distance and possibly avoid the negative conditions.

On the bottom the young clam meets several problems: displacement by currents once it has settled in a particular substratum, destruction by predators, procurement of food in the midst of an aquatic dust storm. Observations reported in this paper indicate how effectively these difficulties are resolved and how well adapted young hard clams are to their coastal environment.

Soon after pediveligers drop to the bottom they secrete a byssus, by means of which they anchor themselves in position. Plantigrades, now noticeably negatively photokinetic, affix to hard surfaces overlain by thin layers of sediment when these are available. This provides a stable anchorage, permits execution of the affixation process under cover of the sediment, and makes available a sedimentary blanket into which plantigrades can burrow away from enemies as they grow. Where such hard surfaces are not present, plantigrades affix the byssus to clusters of sand grains. In channels where swift tidal currents prevail, young clams and their anchorages are moved about by the currents, though probably to a limited degree; just how much has not been reported. Some field observations also suggest that under these circumstances young clams may be concentrated by tidal currents. Whether such concentrations are actually the result of passive accumulation of young clams by water currents, or whether pediveligers were originally attracted to these sites, has not been determined experimentally. Both processes may well operate.

As soon as siphons start to emerge, plantigrades burrow more deeply into the sediment, and away from predators. Since the byssus is readily cast off, plantigrades may crawl easily from an unfavorable site and reaffix quickly in a new location. Siphons, in addition to permitting clams to burrow deeply, point away from each other and deflect incoming and outgoing streams of water, thereby reducing the degree to which a clam recycles water through its mantle cavity. Siphons may be extended at least twice the length of the valves, which permits clams to burrow to this depth and still maintain direct communication with overlying water. Tentacles over the inhalant siphon form a screen which blocks the entrance of larger sedimentary particles. This allows clams to burrow more deeply than permitted by the length of the siphons alone, for the tentacular grid excludes sediments but permits the entrance of interstitial sea water and fine food and sedimentary particles. The depth to which clams may burrow beyond the length of the siphons is not known with certainty, but may be correlated with porosity of sediment. The inhalant tentacular screen makes possible the existence of young clams in unstable sandy bottoms, keeping out the rain of grains roiled by tidal currents. The clams' capacity to dig themselves into and out of sediment makes it possible for them to move vertically in adjustment to fluctuating bottom levels.

Finally, secondary shell rings, though not affording any great resistance to locomotion through the sediment because they tend to parallel direction of movement, do probably constitute friction elevations which offer some resistance to any force drawing the clams vertically out of the bottom.

VI SUMMARY

1. Of the 2,890 *M. mercenaria* employed to obtain gametes over a period of six summers, 12 per cent spawned. We obtained the most abundant and consistent spawnings in New York, and the fewest in North Carolina. The bulk of spawning came in the early summer, and it became increasingly difficult to induce spawning as the season advanced. Retardation of spawning by keeping the clams at low temperatures helped circumvent this difficulty. In all three geographic areas, fully spawning, vigorous females which eliminated ova quickly and abundantly produced the most vigorous, rapidly growing larvae with least mortality.

2. Larvae of the hard clam were reared in the laboratory in New Jersey, New York, and for the first time in North Carolina—most successfully in North Carolina. They were maintained

in large plunger jars, in large still-water culture jars, and individually in microculture dishes. They survived gradual temperature fluctuations ranging between 13°C. and 30°C. A variety of foods including both cultures of mixed micro-organisms dominated by *Chlorella* and by *Nannochloris* and extracts of pablum were provided. The growth rate of larvae was maximal in sea water hauled from the bay and decreased (in progressive reduction) in sea water pumped into the laboratory, in heat-treated sea water, and in charcoal-treated sea water. Lack of uniformity in culturing larvae under apparently similar conditions within single and in different seasons and in different regions suggests that an unidentified substance(s) of sporadic distribution in native waters may be correlated with success in culturing them. The minimum time for development of the larvae to setting stage was eight days. The mortality of the larvae in cultures was highly variable in time and in place.

3. Early stages of *M. mercenaria* pass through a series of recognizable stages characterized by distinct structural features and behavior: non-shelled planktonic stage, straight-hinged veliger, umboned veliger, prodissoconch I, prodissoconch II (veliconcha stage), pediveliger, byssal plantigrade, and juvenile plantigrade. Position and behavior of these stages in the native habitat change with each successive major morphological development.

4. Veliger stages are characterized by smooth valves (prodissoconchs I and II). These are succeeded in the byssal plantigrade first by primary and then by secondary shell ridges. The latter are added throughout the life of the clam. Because of the curvature of these ridges and the behavior of clams in burrowing, the ridges afford a minimum of resistance to locomotion in sediment, but once the animal has become stationary, they aid in anchoring the animal within sediment.

5. Pedal locomotion in pediveligers and newly set plantigrades involves principally ciliary activity; this is superseded by muscular crawling, which permits the animal to burrow within sediment and to emerge from deep sediment when so buried by pushing itself upward with the foot.

6. Shortly after larvae assume the plantigrade habit, and sometimes before the velum is lost, the byssus gland becomes functional and the bivalve begins attachment to substrata by means of the byssus. The byssus increases in size as the animal grows until it reaches shell length of about 9 mm., at which time the byssus gland becomes functionless. The clam makes attachment to an open surface, but attaches more quickly and more frequently when buried under sediment. Affixation of the byssus takes place in a few seconds. It may be dislodged from its origin in the gland when the animal is disturbed and moves on to another site, and dislodgment is performed less readily as the clam increases in size. In the laboratory, the interval between discard and secretion of a new byssus ranged from a few minutes to several hours in different individuals.

7. In veliger and newly set plantigrade clams, sea water moves through the mantle cavity between gaping valves. Soon tissue union of the mantle edges divides the gape into an exhalant and combination pedal-inhalant opening. From the rim of the exhalant opening, there emerges a valvular membrane as the clam develops which controls and directs the exhalant current. At the base of the membrane there next forms the definitive exhalant siphon with its terminal tentacles, which supports the membrane on its outer extremity as it lengthens. The tentaculated inhalant siphon develops as an extension of the mantle edge next to and anteroventrad the exhalant siphon and from the posterior part of the combination inhalant-pedal gape. As the clam reaches adulthood, most of the valvular membrane is resorbed and is represented only by a reduced flange. Siphon tips point away from each other, deflecting incurrent and excurrent water.

8. When byssal plantigrades are buried deep in sediment, tentacles over the siphon tips form protective grids which exclude larger sedimentary grains. These are cleared by slight forceful appression of the valves. As they crawl within sediment, clams continue to pump water, though at a reduced rate probably corresponding to porosity of the overlying sediment. They can emerge from sediment through a depth at least five times the shell length.

9. In the laboratory, trochophore and early straight-hinged veligers are strong swimmers and tend to concentrate in surface layers of water in culture jars. Later-stage veligers remained more or less evenly distributed vertically. Healthy veligers stayed suspended in the water the full period of planktonic existence, quickly returning to suspension if knocked to the bottom, whereas "sick" larvae remained on the bottom except for sporadic swimming efforts.

10. The behavior and ecology of veligers in native waters was studied in Little Egg Harbor, N. J., a shallow coastal plain estuary with a

water-surface area of about 32 square miles. Float and current studies disclosed that in the central basin of Lower Little Egg Harbor the tidal excursion was relatively short as compared with that on the eastern side. Computations of net movements of fresh water into the bay during the summer indicated that slight flushing of bay water into the ocean fluctuated with net flow of sea water into the bay during periods when evaporation rate exceeded rate of fresh-water inflow. The movement of relatively small volumes of fresh water into the bay from all sources, combined with a complex circulation pattern and wind action, produced relatively uniform, high summer salinities throughout the bay and almost eliminated vertical salinity and thermal stratification. Calculation of volume of water in the bay at various stages of the tide showed that exchange was substantial, but because of the unique morphometry and large size of the bay relative to the large cross section and length of the inlet, and with little or no flushing, the mass of water involved in exchange was principally that in the inlet. Thus the central basin of Lower Little Egg Harbor functioned as a retaining vessel of relatively homogeneous sea water in which a large proportion of clam larvae in many instances were held for at least the duration of the veliger stage.

11. Little Egg Harbor has produced high concentrations of hard clams. In the period 1929–1951 estimates of annual yield from the bay ranged from 40,000,000 to 160,000,000 clams.

12. The distribution of hard-clam veligers was studied in the bay over a period of four summers, during which time 1,100 plankton samples were collected. Each summer the largest and most dense swarms appeared during the month of July, and the number and size of spawnings varied from summer to summer. Most major spawnings occurred in a period of two or more days of rising median daily water temperatures: 73 per cent of a total of 67 spawnings took place on rising temperatures, and 27 per cent on falling median daily temperatures; the over-all average median daily spawning temperature was 25.7°C. Spawnings occurred over a median daily range of water temperatures of 22° to 30°C., but the maximum frequency of spawning occurred within the thermal range of 24°–26°C.

13. Spawnings occurred more frequently and more high density swarms of early-stage veligers appeared in the water during neap than during spring tide periods. Higher water temperatures of neap tides probably triggered spawning during this period. Spawning probably took place at or close to the ebb slack period when maximal water temperatures prevailed.

14. When the appearance of veliger swarms in the bay coincided with periods of little or no rainfall and medium to low tidal amplitudes, and thus minimal flushing and exchange, survival rates of veligers from the straight-hinged to the setting stage approximated 2.6 per cent. Conversely, during periods of heavy rainfall and high spring tidal exchanges even very large dense swarms of larvae disappeared from the water.

15. In Little Egg Harbor at median daily water temperatures ranging from 23.4° to 26.2°C. and in salinities fluctuating between 30.4 and 31.4 $^{0}/_{00}$ hard-clam veligers grew to a setting size of about 200 μ from time of fertilization in eight days, an interval comparable with that in the laboratory.

16. Horizontal distribution of veligers in Little Egg Harbor was markedly uneven, though widespread. Maximum densities were found in the lower part of the central basin of the bay; the highest single concentration of straight-hinged veligers encountered there was 67,200 per 100 liters of sea water. In the vicinity of the inlet low densities resulted in part from diluting effect of tidal exchange.

17. For the study of vertical distribution of veligers in the bay, a total of 97 vertical series of plankton samples was collected, and the vertical distribution of straight-hinged and umboned veligers was associated with the stage of the tidal cycle, time of day, relative wind velocity, relative light intensity, and current velocity, and location of various stations in the bay. Veligers appear to maintain themselves suspended in the water throughout planktonic existence. They are generally away from the bottom and bottom-dwelling predators during daylight hours, concentrating in middle strata, and more broadly distributed during hours of darkness, distribution of umboned stages especially extending close to the bottom. Light and turbulence from tidal currents and wave action may stimulate larvae to rise vertically, bringing maximum densities higher in the water during maximal tidal flow and wind velocities and during daylight hours. This needs confirmation. Vertical homogeneity of the water with reference to temperature and salinity precluded association of these factors with vertical distribution of the larvae. Early-stage larvae tended to remain in the original swarms resulting from mass spawning by par-

ents, and in time as a result of hydrographic mixing processes late-stage larvae, apparently unable to counteract horizontal dispersion, became widely and more or less uniformly distributed.

18. Behavior of early byssal plantigrades was studied in the laboratory. They are strongly thigmokinetic and attach the byssus most frequently to hard surfaces covered with thin layers of fine sediment containing appreciable quantities of organic matter; they are also negatively photokinetic, crawling away from light of bright to moderate intensity into areas of dim light. No rheotactic response was elicited in current velocities up to 2.5 cm./sec.

19. Sets of hard clams occurred widely though irregularly througout Little Egg Harbor, and their distribution did not coincide entirely with that of adults. The maximum concentration of byssal plantigrades, 125 per square meter, was located on a shell bar where byssal attachment was made to shells coated with thin layers of mud, confirming similar observations in the laboratory. In the field young clams were often found concentrated most densely in sediment around objects projecting from the bottom. The hypothesis is that this results because: (a) pediveligers may be stimulated to set beneath areas of turbulence differentials, (b) they may crawl or swim into the vicinity of such baffles secondarily after settling elsewhere, and (c) baffle areas provide microhabitats which provide some protection form predators. The response of pediveligers to gradients of turbulence would also stimulate them to settle along edges of channels and sloping portions of bars where they may occur in high densities.

20. A small portable device, the clam-setting indicator, was evolved to take advantage of those characteristics in the setting behavior of pediveligers which stimulate them to affix in indicators and provide a means of determining the relative intensity of setting in the field. These characteristics are (a) possible attraction to gradients of turbulence about objects in the water, (b) preference during daylight for microhabitats in subdued light, (c) preference for contact with shallow layers of fine sediment over hard surfaces. The device excludes predators; does not impede flow of water, food, and oxygen; and permits study of plantigrades within it in a minimal quantity of fine sediment. Maximum density, 202 clams per 0.2 square foot, was obtained in a setting indicator near the bottom in the middle of Little Egg Harbor. Intensity of set was roughly proportional to abundance of late-stage veligers in the plankton preceding the set.

21. Enemies of early stages of the hard clam are described. These include wide variety of plankton feeders, *Sirolpidium*, *Condylostoma*, xanthid mud crabs, *Callinectes*, *Carcinides*, *Limulus*, *Urosalpinx*, *Eupleura*, *Polinices*, *Molgula*, *Sphaeroides*, ducks and geese, and possibly *Busycon* and *Asterias*.

ACKNOWLEDGMENTS

From 1947 to 1952 my research was conducted in co-operation with Dr. T. C. Nelson and Dr. H. H. Haskin as part of a larger project under the direction of Dr. Nelson. We undertook to investigate the biology of *M. mercenaria* to make available information which might be useful in establishing hard-clam farming on a commercial scale. Dr. Nelson and Dr. Haskin contributed generously to planning and organization of my research in New Jersey. During these summers I was assisted by Mr. R. G. Engle (1948), Mr. L. R. Pomeroy (1949–1950), and Mr. H. O. Werntz (1950–1951). In 1949 Mr. J. B. Glude (for U. S. Fish and Wildlife Service) provided supplementary financial aid. Mr. D. Cramer, Mr. F. Huntley, Mr. W. Allen, Mr. F. Morey, and Mr. J. M. Mott, local baymen, extended many courtesies throughout the period. Mr. Mott made available a small cabin beside Thompson Creek, Little Egg Harbor, for our use in the culture of larvae. Mr. K. G. Crosby, U. S. Coast and Geodetic Survey, provided information on tidal data collected in the Edge Cove area. In 1953–1955 on Gardiners Island I was assisted by Mr. R. C. Nelson and for a short time by Mr. G. Sellmer. During this time Mr. J. R. Nelson, president of the J. & J. W. Elsworth Company; Mr. M. C. Gale, owner of the Monarch Buick Company, Inc., and lessee of Gardiners Island; Dr. V. L. Loosanoff; Mr. H. Davis; and Mr. H. N. Gibbs provided support, unusual co-operation, and numerous courtesies. From time to time Dr. Loosanoff contributed algal cultures and young post-set hard clams reared in his laboratory to supplement those reared by us. In 1956 at the Institute of Fisheries Research I was assisted by Mr. J. W. Blake. Dr. T. R. Rice, U. S. Fish and Wildlife Service Radiobiological Laboratory, Beaufort, N. C., made available unialgal cultures of several species of algae. Mr. Elmer Willis provided unspawned clams from Chesapeake Bay. Dr. R. E. Coker identified the copepod *Tisbe*. Dr. A. F. Chestnut and Staff of the Institute extended welcome co-operation and many courtesies. Mr. James E. Grizzle, Department of Biostatistics, University of North Carolina, employing the Univac 1105 of the University of North Carolina Computation Center, developed the statistics reported in this paper. All of these who have made this study possible have my sincere thanks.

Studies in New Jersey were sponsored jointly by Rutgers University and the Campbell Soup Company of New Jersey (1947–1952), with additional aid from the U. S. Fish and Wildlife Service in 1949; those in New York, at first (1952–1954) jointly by the J. &. J. W. Elsworth Company and the Monarch Buick Company, Inc. of New York, and later (1955) jointly by the U. S. Fish and Wildlife Service (through the Oyster Institute of North America) and the Monarch Buick Company, Inc.; those in North Carolina (1956) jointly by the University of North Carolina and the U. S. Fish and Wildlife Service. Financial assistance for final preparation and publication of the manuscript was provided by the University of North Carolina Research Council and the U. S. Fish and Wildlife Service.

J. W. Blake, A. F. Chestnut, J. B. Glude, V. L. Loosanoff, L. R. Pomeroy, G. S. Posner, and H. J. Turner read the manuscript of this paper, and I am grateful for their suggestions and criticisms.

LITERATURE CITED

ANSELL, A. D. 1960. Observations on predation of *Venus striatula* (Da Costa) by *Natica alderi* (Forbes). Proc. Malacolog. Soc. London **34**: 157–164.

———. 1961. Reproduction, growth and mortality of *Venus striatula* (Da Costa) in Kames Bay, Millport. Jour. Mar. Biol. Assoc. U. K. **41**: 191–215.

BAGGERMAN, B. 1953. Spatfall and transport of *Cardium edule* L. Arch. Neerland. Zool. **10**: 315–342.

BELDING, D. L. 1912. A Report upon the Quahaug and Oyster Fisheries of Massachusetts, Including the Life History, Growth and Cultivation of the Quahaug. Dept. Conserv., Commonwealth Mass. Wright and Potter Printing Co.: Boston. 134 pp.

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U. S. Fish & Wildlife Serv. Fish. Bull. **53**: 526–527.

BOUSFIELD, E. L. 1955. Ecological control of the occurrence of barnacles in the Miramichi Estuary. Natl. Mus. Canada Bull. No. 137; Biol. Ser. No. **46**: 1–69.

BROWNE, E. T. 1897. On keeping medusae alive in an aquarium. Jour. Mar. Biol. Assoc. **5**: 176.

BRUCE, J. R., M. KNIGHT, AND M. W. PARKE. 1940. The rearing of oyster larvae on an algal diet. Jour. Mar. Biol. Assoc. **24**: 343.

BUELL, M. F., AND J. E. CANTLON. 1950. A study of two communities of the New Jersey Pine Barrens and a comparison of methods. Ecology **31**: 567–586.

BURKENROAD, M. D. 1957. Intensity of setting of starfish in Long Island Sound in relation to fluctuations of the stock of adult starfish and in the setting of oysters. Ecology **38**: 164–165.

CARRIKER, M. R. 1950a. Notes on the killing and preservation of bivalve larvae in fluids. Nautilus **64**: 14–17.

———. 1950b. Some recent investigations of native bivalve larvae in New Jersey estuaries. Proc. Natl. Shellfish Assoc. **1950**: 69–74.

———. 1951a. Observations on the penetration of tightly closing bivalves by *Busycon* and other predators. Ecology **32**: 73–84.

———. 1951b. Ecological observations on the distribution of oyster larvae in New Jersey estuaries. Ecol. Monogr. **21**: 19–38.

———. 1952. Preliminary studies on the field culture, behavior, and trapping of the larvae of the hard clam *Venus* (*Mercenaria*) *mercenaria* L. Natl. Shellfish. Assoc. Conv. Addresses **1952**: 70–73.

———. 1956. Biology and propagation of young hard clams, *Mercenaria mercenaria*. Jour. Elisha Mitchell Sci. Soc. **72**: 57–60.

———. 1957. Preliminary study of behavior of newly hatched oyster drills, *Urosalpinx cinerea* (Say). Jour. Elisha Mitchell Sci. Soc. **73**: 328–351.

———. 1959. The role of physical and biological factors in the culture of *Crassostrea* and *Mercenaria* in a salt-water pond. Ecol. Monogr. **29**: 219–266.

———. 1961. Use of a mobile floating laboratory for ecological estuarine research. Ward's Nat. Sci. Bull. **34** (2): 3–7, 26–27.

CHANLEY, P. 1958. Survival of some juvenile bivalves in water of low salinity. Proc. Natl. Shellfish. Assoc. **48**: 52–65.

CHESTNUT, A. F. 1952. Growth rates and movements of hard clams, *Venus mercenaria*. Proc. Gulf Carib. Fish. Inst. 4th Ann. Sess. 49–59.

COAST AND GEODETIC SURVEY. 1941. Manual of Tide Observations. Spec. Publ. No. 196, Rev. ed., U. S. Gov't. Printing Office, Wash. 92 pp.

COLE, H. A. 1938. The fate of the larval organs in the metamorphosis of *Ostrea edulis*. Jour. Mar. Biol. Assoc. U. K. **22**: 469–488.

DAVIS, H. C. 1958. Survival and growth of clam and oyster larvae at different salinities. Biol. Bull. **114**: 296–307.

DAVIS, H. C., AND P. E. CHANLEY. 1956. Effects of some dissolved substances on bivalve larvae. Proc. Natl. Shellfish. Assoc. **46**: 59–74.

DAVIS, H. C., AND R. R. GUILLARD. 1958. Relative value of ten genera of microorganisms as foods for oyster and clam larvae. U. S. Fish & Wildlife Serv. Fish. Bull. **58**: 291–304.

DAVIS, H. C., V. L. LOOSANOFF, W. H. WESTON, and C. Martin. 1954. A fungus disease in clam and oyster larvae. Science **120**: 36–38.

de Blok, J. W., and Hannie J. Geelen. 1958. The substratum required for the settling of mussels (*Mytilus edulis* L.). Arch. Neerland. Zool., Suppl. **1** to **13**: 446–460.

Dew, Barbara, and E. J. Wood. 1955. Observations on periodicity in marine invertebrates. Australian Jour. Mar. & Freshwater Res. **6**: 469–478.

Feen, P. J. van der. 1949. Byssus. Basteria **13**: 66–71.

Frissell, D. L. 1936. Primary reclassification of veneracean pelecypods. Bull. Mus. Roy. d'Hist. Nat. Belgique **12** (34): 1–84.

Gaarder, T., and P. Bjerkan. 1934. Østers og Østerskultur i Norge. A. S. John Grieg, Bergen.

Hanks, J. E. 1960. The Early Life history of the New England Clam Drills, *Polinices duplicatus* (Say), *Polinices heros* (Say), and *Polinices triseriata* (Say) (Naticidae: Gastropoda). Unpublished Ph.D. dissertation, University of New Hampshire. 122 pp.

Hulbert, E. M. 1957. The distribution of *Neomysis americana* in the estuary of the Delaware River. Limnol. & Oceanogr. **2**: 1–11.

Hunter, W. R. 1949. The structure and behavior of *''Hiatella gallicana''* (Lamarck) and *''H. arctica''* (L.), with special reference to the boring habit. Proc. Roy. Soc. Edinburgh Sec. B. **63** (3) (19): 271–289.

Jenner, C. E. 1956. The occurrence of a crystalline style in the marine snail, *Nassarius obsoletus*. Biol. Bull. **111**: 304 (abstract).

Jørgensen, C. B. 1946. Lamellibranchia *in* Reproduction and larval development of Danish marine bottom invertebrates by G. Thorson. Medd. Komm. Danmarks Fish. Havunders. Ser. Plankton **4**: 277–311.

Kellogg, J. L. 1892. A contribution to our knowledge of the morphology of lamellibranchiate mollusks. Bull. U. S. Fish. Comm. **10** (for 1890): 389–436.

———. 1901. Clam and scallop industries of New York State. Bull. N. Y. Sta. Mus. No. 43, vol. **8**: 605–629.

Korringa, P. 1940. Experiments and observations on swarming, pelagic life and setting in the European flat oyster, *Ostrea edulis* L. Arch. Neerland. Zool. **5**: 1–249.

Landers, W. S. 1954. Seasonal Abundance of Clam Larvae in Rhode Island Waters, 1950–52. U. S. Fish & Wildlife Serv. Spec. Sci. Rept.—Fish. No. 117.

Lebour, M. V. 1933. Rearing marine animals in a plunger. Sci. Progr. **107**: 494–502.

Lindsay, C. E., and C. E. Woelke. 1960. Production of clam and oyster seed. In Fisheries, Vol. III, by M. Moore, K. McLeod, and D. Reed (Wash. Sta. Dept. Fish.), pp. 81–85.

Loosanoff, V, L. 1937a. Development of the primary gonad and sexual phases in *Venus mercenaria* Linnaeus. Biol. Bull. **72**: 389–405.

———. 1937b. Spawning of *Venus mercenaria* (L.). Ecology **18**: 506–515.

———. 1953. Lack of relation between age of oysters or clams and quality of their spawn. U. S. Fish & Wildlife Fish. Biol. Lab., Milford, Conn., Bull. **17** (4): 1–2.

———. 1954. New advances in the study of bivalve larvae. Amer. Sci. **42**: 607–624.

———. 1958. Challenging problems in shellfish biology. In Perspectives in Marine Biology, A. A. Buzzati-Traverso, ed. Berkeley and Los Angeles: University of California Press.

———. 1959a. *Condylostoma*—an enemy of bivalve larvae. Science **129**: 147.

———. 1959b. The size and shape of metamorphosing larvae of *Venus* (*Mercenaria*) *mercenaria* grown at different temperatures. Biol. Bull. **117**: 308–318.

Loosanoff, V. L., and H. C. Davis. 1950. Conditioning of *V. mercenaria* for spawning in winter and breeding its larvae in the laboratory. Biol. Bull. **98**: 60–65.

——— and ———. 1951a. Delayed spawning of lamellibranchs by low temperature. Jour. Mar. Res. **10**: 197–202.

Loosanoff, V. L., H. Davis, and P. Chanley. 1953. Effect of overcrowding on rate of growth of clam larvae. Anat. Rec. **117**: 645 (abstract).

———, ———, and ———. 1953b. Behavior of clam larvae in different concentrations of food organisms. Anat. Rec. **117**: 586 (abstract).

Loosanoff, V. L., and J. B. Engle. 1942. Use of complete fertilizers in cultivation of microorganisms. Science **95**: 487–488.

Loosanoff, V. L., J. E. Hanks, and A. E. Ganaros. 1957. Control of certain forms in zooplankton in mass algal cultures. Science **125** (3257): 1092–93.

Loosanoff, V. L., W. S. Miller, and P. B. Smith. 1951b. Growth and setting of larvae of *Venus mercenaria* in relation to temperature. Sears Found. Jour. Mar. Sci. **10**: 59–81.

Lynch, W. F. 1959. Factors influencing metamorphosis of larvae of some of the sessile organisms. XVth Internatl. Congr. Zool. London, Proc.: 239–241.

Manning, J. H., and H. H. Whaley. 1954. Distribution of oyster larvae and spat in relation to some environmental factors in a tidal estuary. Proc. Natl. Shellfish. Assoc. **45**: 56-65.

Martin, A. C., and F. M. Uhler. 1939. Food of Game Ducks in the United States and Canada. U. S. Dept. Agr. Tech. Bull. 634. 157 pp.

Morton, J. E. 1960. The responses and orientation of the bivalve *Lassaea rubra* Montagu. Jour. Mar. Biol. Assoc. U. K. **39**: 5–26.

Nelson, T. C. 1921. Aids to successful oyster culture. I. Procuring the seed. N. J. Agr. Exper. Sta. Bull. **351**: 4–59.

Nelson, T. C., and H. H. Haskin. 1949. On the spawning behavior of oysters and of *Venus mercenaria* with especial reference to the effects of spermatic hormones. Anat. Rec. **105**: 484–485 (abstract).

NELSON, T. C., AND E. B. PERKINS. 1931. Annual Report of the Department of Biology for the year ending June 30, 1930. N. J. Agr. Exper. Sta.

ORTON, J. H. 1937. Some interrelations between bivalve spatfalls, hydrography and fisheries. Nature **140**: 505–506.

POMEROY, L. R., H. H. HASKIN, R. A. RAGOTZKIE. 1956. Observations on dinoflagellate blooms. Limnol. & Oceanogr. **1**: 54–60.

PRITCHARD, D. W. 1951. The physical hydrography of estuaries and some applications to biological problems. Trans. 16th North Amer. Wildlf. Conf., Wildlife Management Institute: 368 376.

———. 1952. Salinity distribution and circulation in the Chesapeake Bay estuarine system. Jour. Mar. Res. **11**: 106–123.

———. 1955. Estuarine circulation patterns. Proc. Amer. Soc. Civil Engineers **81**: 1–11.

PRITCHARD, D. W., AND R. E. BUNCE. 1959. Physical and Chemical Hydrography of the Magothy River. Chesapeake Bay Institute, Johns Hopkins Univ., Tech. Rept. 17.

QUAYLE, D. B. 1949. Movements in *Venerupis* (*Paphia*) *pullastra* (Montagu). Proc. Malacol. Soc. London **28**: 31–37.

———. 1952. Structure and biology of the larva and spat of "*Venerupis pullastra*" (Montagu). Trans. Roy Soc. Edinburgh **62** (1) (8): 255 297.

RAGOTZKIE, R. A. AND R. A. BRYSON. 1953. Correlation of currents with the distribution of adult *Daphnia* in Lake Mendota. Jour. Mar. Res. **12**: 157–172.

RAVEN, C. P. 1958. Morphogenesis: The Analysis of Molluscan Development. New York: Pergamon Press.

REES, C. B. 1950. The identification and classification of lamellibranch larvae. Hull Bull. Mar. Ecol. **3**: 7–103.

RICE, T. R. 1953. Phosphorus exchange in marine phytoplankton. U. S. Fish & Wildl. Serv. Fish. Bull. **54**: 76 89.

RICE, T. R., AND REBECCA J. SMITH. 1958. Filtering rates of the hard clam (*Venus mercenaria*) determined with radioactive phytoplankton. Fish. Bull. U. S. Fish. & Wildlife Serv. **58**: 73–82.

RICHARDS, O. W. 1933. Toxicity of some metals and Berkefeld filtered sea water to *Mytilus edulis*. Biol. Bull. **65**: 371–372.

RYDER, J. A. 1889. The byssus of the young of the common clam *Mya arenaria* L. Amer. Nat. **23**: 65–67.

SAWYER, D. B. 1950. Feeding activities of the boring snail *Polynices duplicata*. 3rd Rept. Invest. Methods Improving Shellf. Res. Mass., Commonwealth of Mass., Dept. Conserv., Div. Mar. Fish.: 16–17.

SCHEFFÉ, H. 1959. The Analysis of Variance. New York: John Wiley & Sons, Inc. Pp. 331-368.

SELLMER, G. P. 1959. Studies on the Anatomy and Life History of the Gem Clam, *Gemma gemma* (Totten). Unpublished Ph.D. dissertation, Rutgers University, New Brunswick, N. J. Pp. 237.

SHUSTER, C. N. 1950. Observations on the natural history of the American horseshoe crab *Limulus polyhemus*. 3rd Rept. Invest. Methods Improving Shellfish. Res. Mass. Commonwealth of Mass. Dept. Conserv., Div. Mar. Fish.: 18-23.

———. 1951. On the migration of young *Polynices*. Anat. Rec. **111**: 542 (abstract).

STAFFORD, J. 1912. On the recognition of bivalve larvae in plankton collections. Contr. Canadian Biol. 1906–10: 221 242.

SULLIVAN, C. M. 1948. Bivalve larvae of Malpeque Bay, P.E.I. Fish. Res. Bd. Canada Bull. **78**: 1–36.

SVERDRUP, H. V., M. W. JOHNSON, AND R. H. FLEMING. 1942. The Oceans. Their Physics, Chemistry, and General Biology. New York: Prentice-Hall, Inc.

THORSON, G. 1946. Reproduction and larval development of Danish marine bottom invertebrates, with special reference to the planktonic larvae in the sound (Øresund). Medd. Komm. Danmarks Fisk. Havunders. Ser. Plankton **4**: 1–523.

———. 1950. Reproductive and larval ecology of marine bottom invertebrates. Biol. Rev. Cambridge **23**: 1–45.

———. 1957. Bottom communities. Chapt. 17 in Treatise on Marine Ecology and Paleoecology, vol. 1, memoir 67, Geol. Soc. Amer.: 461–534.

TURNER, H. J. 1953. A review of the biology of some commercial molluscs of the east coast of North America. 6th Rept. Invest. Shellf. Mass., Dept. Nat. Res., Div. Mar. Fish., Commonwealth Mass.: 39-74.

TURNER, H. J., AND C. J. GEORGE. 1955. Some aspects of the behavior of the quahaug, *Venus mercenaria*, during the early stages. 8th Rept. Invest. Shellf. Mass., Dept. Nat. Res., Div. Mar. Fish., Commonwealth Mass.: 5–14.

U. S. GEOLOGICAL SURVEY. 1948-1951. Surface Water Supply of the United States. Part I. North Atlantic Slope Basins. Water-supply Papers 1111, 1141, 1171, 1202. U. S. Geol. Surv., U. S. Dept. Int., U. S. Gov't. Printing Office, Wash.

U. S. WEATHER BUREAU. 1948–1951. Climatological data, New Jersey. U. S. Weather Bur., U. S. Dept. Commerce.

WELLS, H. W. 1957. Status of the name *Venus*. Ecology **38**: 160–161.

WELLS, W. F. 1927. Report of experimental shellfish station. 16th Ann. Rept. **1926**: 1–22.

WERNER, B. 1939. Uber die Entwicklung und Artunterscheidung von Muschellarven des Nordseesplanktons, unter besonderer Berucksichtigung der Schalenentwicklung. Zool. Jahrb., Abt. Anat. **66**: 1–54.

WINSOR, C. P. AND G. L. CLARK. 1940. A study of variation in the catch of plankton nets. Jour. Mar. Res. **3**: 1–34.

YONGE, C. M. 1957. Mantle fusion in the lamellibranchia. Pubbl. Staz. Zool. Napoli **26**: 151–171.

17

COMPARATIVE FUNCTIONAL MORPHOLOGY OF BORING MECHANISMS IN GASTROPODS

Melbourne Romaine Carriker
Department of Zoology, Chapel Hill
and
Institute of Fisheries Research, Morehead City
University of North Carolina

Reprinted from
American Zoologist
Vol. 1, No. 2, p. 263-266
1961

AM. ZOOLOGIST, 1:263-266 (1961).

COMPARATIVE FUNCTIONAL MORPHOLOGY OF BORING MECHANISMS IN GASTROPODS

MELBOURNE ROMAINE CARRIKER
Department of Zoology, Chapel Hill, and Institute of Fisheries Research,
Morehead City, University of North Carolina

Organisms capable of perforating the calcareous exoskeleton of other organisms are represented in the algae, fungi, bacteria, and in at least 7 animal phyla. Better known genera of the latter are: the sponge *Cliona,* the flatworm *Pseudostylochus,* the bryozoan *Ctenostomata,* the phoronid *Phoronis,* the polychaete *Polydora,* the barnacle *Trypetesa,* the pelecypod *Lithophaga,* and the gastropod *Natica.*

The mechanism by which penetration is effected is incompletely understood. Among plants and lower invertebrates it may be achieved by chemical means alone; in higher invertebrates, by mechanical, chemical, or a combination of these. Various hypotheses suggest that release of CO_2, mineral acids, organic acids, enzymes, or sequestering agents may bring about dissolution of shell. A current theory on formation of dental caries in humans postulates that proteolytic-chelating substances released by bacteria and/or fungi may cause simultaneous dissolution of the organic matrix and enamel apatite of teeth. In higher invertebrates mechanical devices such as valve edges in pelecypods, radulae in gastropods, and bristles in polychaete and sipunculid worms and in barnacles may be employed alone in penetration of soft calcareous substrates; but perforation of hard exoskeletons probably requires chemomechanical means. The degree of similarity of the chemical mechanism for shell dissolution in this wide assortment of organisms can only be conjectured at this time. Descriptive and experimental studies in progress by the writer on boring mechanisms in muricid, thaidid, and naticid prosobranch gastropods contribute further information on boring mechanisms and support a chemo-mechanical theory of penetration in which abrasive action of the radula removes shell softened by secretion from the accessory boring organ, the ABO.

It has been recognized for at least 2,300 years that certain predatory gastropods obtain food through holes drilled by them in the calcareous exoskeletons of prey. At present such boring is attributed to species in 6 families: Cymatiidae, Muricidae, Thaididae, and Naticidae (prosobranchs); and Helicidae and Oleacinidae (pulmonates). Little is known about boring in the Cymatiidae, Helicidae, and Oleacinidae. Members of the families Cassidae, Doliidae, and Tritonidae (prosobranchs) are said to secrete acid which may serve in boring or dissolving echinoderm prey. The method of penetration of the prey is poorly understood and requires further study. In Naticidae the ABO is borne on the ventral tip of the proboscis and was first described by Troschel (1854). Schiemenz (1891) first suggested that this ABO secretes an acid, but this has not been confirmed. Ankel (1937, 1938), by placing freshly cut naticid ABOS against the shell, obtained shallow dissolution in a few hours and postulated the presence of a calcase. The ABO in Muricidae

---

Thanks are gratefully extended to the staff of the University of North Carolina Institute of Fisheries Research where most of this research was carried out; to research assistants John W. Blake and Virginia M. Willis; to malacologists in different parts of the world for collection and shipment of gastropods; to William J. Clench and Ruth D. Turner, Museum of Comparative Zoology, Harvard University, for final identification of gastropods; to Jorgen Knudsen, Universitetets Zoologiske Museum, Denmark, for making available bored deep-sea molluscs collected by the Galathea Expedition of 1950-52; to Ellis L. Yochelson, U. S. Geological Survey, for collaboration in study of fossil bore holes; to David B. Scott and Billie Ann Hernandez, National Institute of Dental Research, for collaboration in preparation of electron micrographs of ABO etchings on shell; and to the U. S. Fish and Wildlife Service for financial support of these studies.

Present address: Biological Laboratory, U. S. Bureau of Commercial Fisheries, Oxford, Maryland.

was discovered independently by Fretter (1941, 1946), who considered it a pedal sucker, and by the writer (1943) who concluded from behavioral studies that it secretes a shell-softening substance.

Study by us of bore holes collected by the Galathea Expedition in 1950-1952, as well as those drilled by snails in our laboratory, suggests that boring gastropods are present in most of the shallower portions of the oceans to a depth of at least 2,700 meters. The oldest gastropod bore holes which we have been able to identify are some 400 million years old from the Middle Ordovician, and suggest the antiquity of the origin of the boring mechanism.

To date 29 different species of boring and several species of non-boring marine predatory gastropods from 21 different areas of the world (including England, Scotland, Canada, the three major coasts of the United States, Puerto Rico, Bimini, Japan, Korea, Vietnam, and Australia) have been studied. From distant points live snails were mailed to us by air, in small quantities of sea water in plastic bags held in stout perforated containers. Snails were maintained in running sea water with bivalves to permit them to bore holes (Fig. 1). Presence or absence, form, and dimensions of the following were associated for each species: bore hole, radula expanded normally over odontophore, salivary glands, accessory salivary glands, pyriform organ, gland and duct of Leiblein, and ABO—structures possibly related to boring. To permit study and drawing of the minute anatomy of these organs, snails were relaxed by means of a Sevin-CO_2-freeze technic (Carriker and Blake, 1959). Serial histological sections of ABO and organs of the cephalic hemocoel of most species were prepared to supplement minute anatomical studies.

The ABO is present in all 29 species of boring species examined; in the sole of the foot of 24 Muricidae and Thaididae, and under the distal tip of the proboscis in 5 Naticidae. In *Bedeva hanleyi*, *Eupleura caudata caudata*, *E. c. etterae*, *E. c. sulcidentata*, *Murex brevifrons*, *M. cellulosus*, *M. florifer arenarius*, *M. fulvescens*, *M. pomum*, *Muricopsis ostrearum*, *Ocenebra erinaceus* *O. japonica*, *Pterorytis foliata*, *Thais del toidea*, *T. emarginata*, *T. lamellosa*, *T. la pillus*, *T. rustica*, *Urosalpinx cinerea cin erea*, *U. c. follyensis*, *U. perrugata*, and *U tampaensis*, the ABO appears as a separate or gan in the anterior mid-ventral portion o the foot, anterior to the egg capsule glan in the female—except in those of the specie of *Bedeva*, *Murex*, and *Muricopsis* liste here which lacked an egg capsule glan

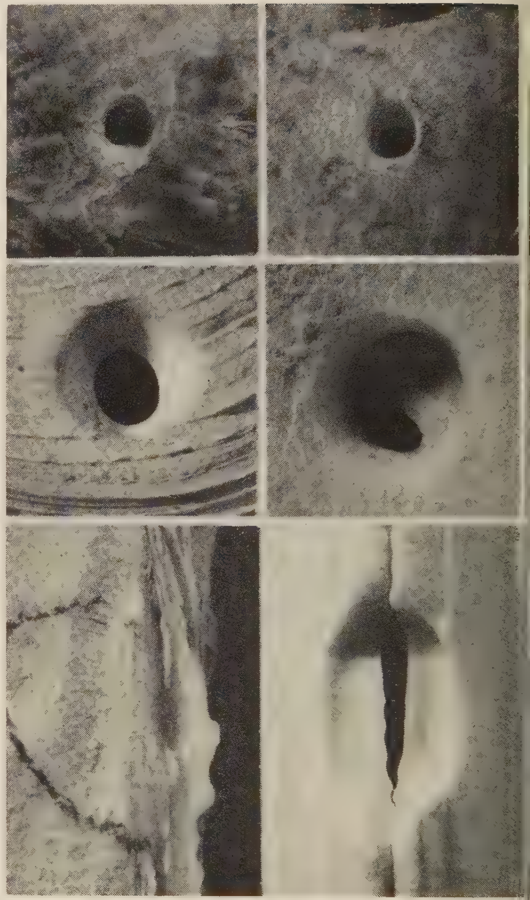


FIG. 1. Some representative gastropod bore holes upper left, bore hole drilled by *Ocenebra erinacea* (from England) in shell of *Crassostrea virginica* upper right, by *Bedeva hanleyi* (Australia) in *C* *virginica*; middle left, by *Natica severa* (Korea) in *Mercenaria mercenaria*; middle right, by *Murex* *brevifrons* (Puerto Rico) in *C. virginica*; lower left by *Thais haemastoma floridana* (North Carolina in *C. virginica*; lower right, by *Murex fulvescens* (North Carolina) in *M. mercenaria*. 5 ×. (Photo graphs by S. M. Boone and M. R. Carriker.)

hen examined. In *Thais clavigera, Ra- ana thomasiana, Thais haemastoma, T. h. oridana,* and *T. h. haysae,* the ABO lies top, and is continuous with, the egg cap- ule gland, so that in eversion the ABO passes hrough the cavity of the egg capsule gland; hese snails are all effective borers. Two mall arteries and two nerves pass to the BO from the cephalic hemocoel. Absence f accessory salivary glands in *Murex po- um* and their extremely small size in *Bede- a hanleyi, M. fulvescens,* and *M. f. arenari- s* depreciates the possible role of these lands in the boring process—as does the act, reported by Graham (1941), that secre- ion of the accessory salivary glands of *T. apillus* has a pH of 6 and does not etch hell or dissolve shell flakes. In Naticidae *Lunatia lewisi, Natica severa, Neverita di- lyma, Polinices duplicatus, Sinum perspec- ivum*) accessory salivary glands are likewise acking. Histologically the distal cap of the BO in all borers consists of a very tall, cili- ated, glandular epithelium different from ny other tissue in these snails. Non-boring redatory snails, like *Buccinum undatum* nd *Neptunea decemcostata,* lack an ABO nd accessory salivary glands, and their pro- boscides and radulae are equipped for tear- ing and pulling flesh rather than for rasp- ing shell.

The proboscis was amputated from each of 16 adult *Urosalpinx cinerea* and 16 adult *Eupleura c. etterae* (equal number of both sexes), and the ABO from a similar sample. Patients were housed with oysters in separate containers in running sand-filtered sea water. All snails survived. In proboscisectomized snails, resumption of drilling in different individuals varied from the 11th to the 34th day after excision; in ABO-ectomized snails, from the 8th to the 25th day. In every case drilling snails possessed fully formed, though small, radulae and ABOS. Length of radula at time of resumption of boring ranged from 1.5 to 5.0mm in snails whose radulae normally ranged from 7 to 11 mm in length. Of the 64 excised snails, only one large, ABO-ectomized female *U. cinerea* did not resume drilling: when dissected after 67 days she had not regenerated the ABO. Other studies on rate of regeneration of the ABO and proboscis showed that no snail resumed boring until both these organs had achieved at least miniature forms of those in normal animals.

By means of the Prytherch viewer (a live shucked oyster held in a cupped oyster valve sandwiched between two glass slides in sea water) we demonstrated repeatedly that *Urosalpinx* and *Eupleura* alternate use of ABO and radula during boring. In early stages of perforation the snail spends most of its time rasping periostracum from the shell surface and exploring the boring site with propodium and proboscis tip. After active boring begins the snail rasps steadily at the boring site for a few minutes, then retracts the proboscis bringing the ABO directly over the hole, extends the ABO into the hole, and leaves it there, tightly sealed from outside seawater by the ventral surface of the foot for periods varying from a few to 55 minutes; it then withdraws the ABO and continues rasping.

Secretion of the ABO, whether from the retracted or the extended and functioning gland, is neutral. ABOS excised from several individuals of 16 of the species of borers listed above and placed on smooth shell in a moist chamber (Ankel, 1937) produced marks on the shell surface ranging from faint etchings to slight depressions the shape and size of the gland. Even though the glands were placed on shell in a drop of sea water two to three times the diameter of the ABO, etchings occurred only under the gland, often leaving sharp boundaries between etched and unaffected shell surface. No erosion took place under control tissues from other parts of the body. Optical and electron micrographs of metal-shadowed collodion and collodion-carbon replicas and pseudo-replicas of these etchings show that the secretion softens and loosens the surface crystals of shell calcite; it also etches the surface of non-biological inorganically deposited calcite and aragonite crystals. Action of the secretion on the conchiolin (freed of calcite with disodium ethylene diamene tetraacetate) of the shell, and nature of the secretion are under study.

REFERENCES

Ankel, W. E. 1937. Wie bohrt *Natica?* Biol. Zentr. 57:75-82.

Ankel, W. E. 1938. Erwerb und Aufnahme der Nahrung bei den Gastropoden. Zool. Anz. Suppl., 11:223-295.

Carriker, M. R. 1943. On the structure and function of the proboscis in the common oyster drill, *Urosalpinx cinerea* Say. J. Morph., 73:441-498.

Carriker, M. R., and J. W. Blake. 1959. A method for full relaxation of muricids. Nautilus 73:16-21.

Fretter, Vera. 1941. The genital ducts of some British stenoglossan prosobranchs. J. Mar. Biol. Asso U. K. 25:173-211.

———. 1946. The pedal sucker and anal gland o some British Stenoglossa. Proc. Malacological So London 27:126-130.

Graham, A. 1941. The oesophagus of the stenoglossan prosobranchs. Proc. Roy. Soc. Edinburg 61B:1-22.

Schiemenz, P. 1891. Wie bohrt *Natica* die Muschel an? Mitt. Zool. Sta. Neapel 10:153-169.

Troschel, F. H. 1854. Ueber die Speichel von *Dolium galea*. J. prakt. Chemie 63:170-179.

18

INHERITANCE OF SHELL MARKINGS AND GROWTH IN THE HARD CLAM, VENUS MERCENARIA

Paul E. Chanley

U. S. Fish and Wildlife Service, Milford, Conn.

ABSTRACT

Inheritance of Venus mercenaria (Mercenaria mercenaria) notata shell markings was followed through two generations. Offspring from three crosses of unmarked "white" clams were unmarked, while three crosses of white clams with clams having the "notata" marking, produced about half unmarked offspring and about half marked with the reddish-brown zigzag lines, typical of notata subspecies. When two clams with notata shell markings were crossed, about one-fourth of the offspring were unmarked and about half were marked with zigzag lines. The remaining one-fourth were almost solidly reddish-brown, with a light band from the umbo around the lunule, and two other light bands from the umbo to the margin of the shell, dividing it roughly into thirds. This marking is considered typical of clams homozygous for the color factor. The zigzag lines, which are commonly used to identify the notata subspecies, are considered the phenotypic markings of heterozygous clams.

Offspring from fast-growing sibling clams were 60 per cent larger, after 15 months, than offspring from clams randomly selected from wild stock. This suggests that only a few generations would be required to develop fast-growing races of clams.

INTRODUCTION

Advances in the laboratory culture of lamellibranch larvae have made possible the rearing of shellfish of known parentage. Because of these advances, studies of inheritance in shellfish are now possible. Knowledge of the principles of inheritance has permitted great improvements in agriculture in the past and knowledge of the principles of molluscan inheritance may be as beneficial to modern shellfish cultivation in the future.

Because of length of time required and difficulty in rearing larval stages, genetic studies of commercial bivalves are scarce. Interspecific crosses have been reported by Bouchon-Brandely (1883) and Davis (1950). Survival and growth of V. mercenaria, V. campechiensis and their hybrids have been studied in Virginia by Haven and Andrews (1957) and in North Carolina by Chestnut, Fahy and Porter (1957). Chanley (1955) reported that clam larvae from one set of parents grew more rapidly than those from other parents, but dealt only with larvae. Davis (1955) reared five generations of Olympia oysters (Ostrea lurida)

Reprinted from PROCEEDINGS OF THE NATIONAL SHELLFISHERIES ASSOCIATION, Volume 50, 1961

Table 1. Comparison of observed ratios of marked and unmarked offspring with those expected if the notata marking is a simple Mendelian character. The value of X^2 is given with the probability of a higher value of X^2 occurring by chance.

Cross	Observed Ratio		Expected Ratio		X^2	P
	Unmarked	Marked	Unmarked	Marked		
Parent Generation						
Marked* ♀ (A) x unmarked ♂ (A)	248	246	247	247	.008	> .90
Marked* ♀ (A) x marked* ♂ (B)	297	913	302.5	907.5	.133	> .70
F_1 Generation from ♀ (A) x ♂ (A)						
Unmarked ♀ (1) x unmarked ♂ (1)	968	32	1000	0	∞	
Unmarked ♀ (2) x unmarked ♂ (1)	999	1	1000	0	∞	
Unmarked ♀ (3) x unmarked ♂ (1)	999	1	1000	0	∞	
Unmarked ♀ (1) x marked* ♂ (2)	501	499	500	500	.004	.95
Marked* ♀ (4) x unmarked ♂ (1)	510	490	500	500	.400	> .50
Marked* ♀ (4) x marked* ♂ (2)	233	767	250	750	1.541	> .20

* Parent clams, listed as marked, have the typical reddish-brown zigzag lines commonly considered characteristic of the notata subspecies and illustrated as heterozygous in Fig. 1.

in an unsuccessful attempt to develop a strain that would survive New England winters, but there are few reports involving more than one generation.

The purposes of these experiments were (1) to study inheritance of the typical reddish-brown shell markings of V. mercenaria notata, and (2) to determine the feasibility of developing fast-growing races of hard clams by selective breeding.

RESULTS

Inheritance of Notata Markings

The subspecies V. mercenaria notata is easily identified by typical reddish-brown zigzag lines on both valves of the shell (Abbott 1954). It occurs along the east coast from Maine to Florida but is rather uncommon particularly over the northern part of its range (Miner 1950, Morris 1956). This form is rarely seen in Long Island Sound not only because it is uncommon but also because the shell markings are frequently obscured by shell discoloration caused by the substrate.

In studies of the inheritance of notata markings, two original crosses of Long Island Sound clams were involved. In each case female A, displaying notata markings, was used. In the first cross this female was crossed with unmarked male A. The ratio of notata-marked to unmarked offspring was close to the 1 to 1 ratio expected when a heterozygous individual is crossed with a homozygous recessive one (Table 1). When the same female, A, was crossed with male B, also bearing the notata markings, the ratio of marked to unmarked offspring was essentially 3 to 1. This is the expected phenotypic ratio in a cross of two individuals heterozygous for a simple Mendelian character.

Counts were not made until marked and unmarked clams had reached a minimum length of about 5 mm, since the notata markings were not always apparent in smaller clams. Even at this size markings were sometimes faint and difficult to detect. Subsequent counts, however, failed to show any appreciable change from the original ratios.

Offspring from the cross of marked female A with unmarked male A were raised to maturity and used in another series of crosses. Progeny from the female A by male B cross were not yet large enough to give adequate amounts of spawn at this time. Improved techniques in culture methods provided more clams than could be conveniently examined in these crosses and, therefore, random samples of 1,000 were counted.

The first three crosses of the F_1 generation involved unmarked clams (Table 1). Although a few marked clams were found among the offspring, we believe that these crosses actually produced no marked clams. It is possible that they were introduced accidentally from other groups during the handling that was necessary to rear the clams from eggs to more than a year old.

Both F_1 crosses involving a marked clam with an unmarked clam produced offspring roughly in a ratio of 1 marked to 1 unmarked. This is again the expected ratio for a cross of a heterozygous individual with a homozygous recessive.

When two notata-marked clams from the F_1 generation were crossed the offspring bore notata markings in a 3 to 1 ratio as expected in a cross involving heterozygous individuals. In this last cross two types of markings could be recognized (Fig. 1). The most common markings were the typical reddish-brown zigzag lines. This marking was quite variable and ranged from faint fragments of lines to dark, heavy lines so concentrated that they produced almost a solid color. The other type of marking also varied, but typically the shells were almost solidly colored reddish-brown with a light band from the umbo around the lunule. Two other broad light bands extended from the umbo to the margin of the shell, dividing it roughly into thirds. The zigzag lines occurred only in lighter areas of the shell. Although this marking has not been described for the notata subspecies, it is probably the coloration characteristic of clams homozygous for the color factor, since it occurred only when two notata-marked clams were crossed. Apparently the more familar zigzag lines, accepted as characteristic of the notata subspecies, are actually a phenotypic blend exhibited by heterozygous clams.

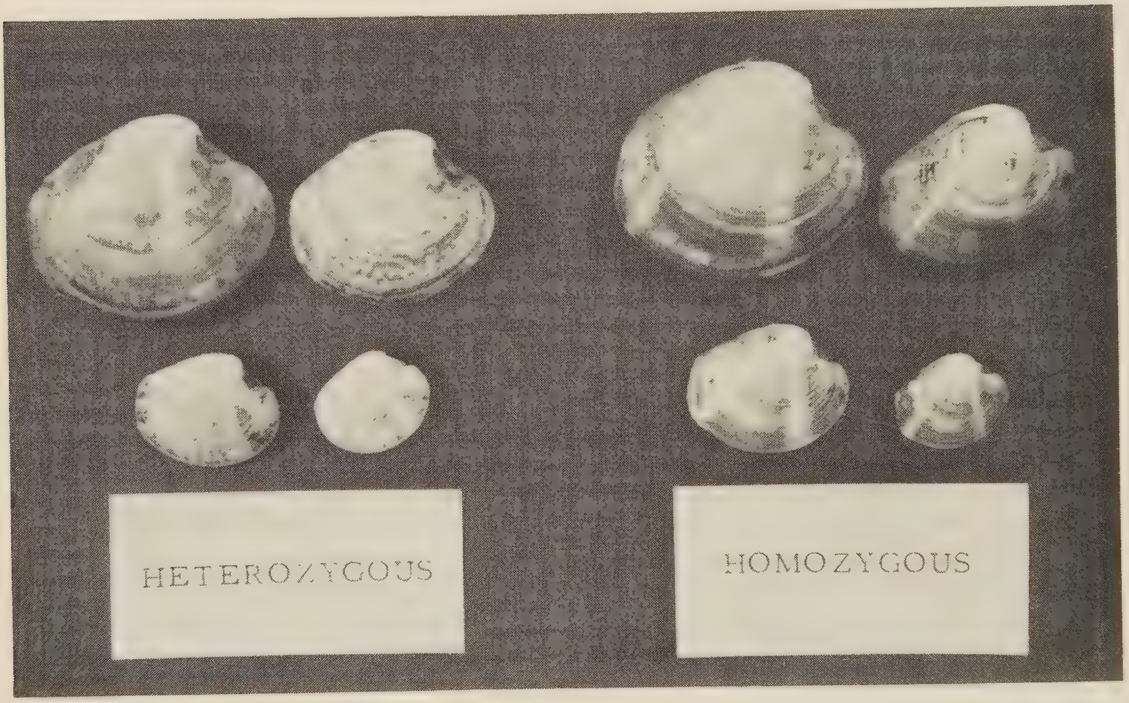


Fig. 1. Juvenile _V. mercenaria notata_ showing the difference between homozygous and heterozygous markings.

A count based on these different markings gave 233 unmarked, 507 marked with zigzag lines, and 260 solidly colored with light bands. This is roughly the expected 1 to 2 to 1 genotypic ratio resulting when two heterozygous individuals are crossed. Chi square in this case is equal to 1.654, a value that would occur by chance in over 30 per cent of such crosses. Unfortunately, time and space limitations did not permit raising these clams so that homozygous marked clams could be crossed.

If we assume that the notata marking is a simple Mendelian character, either with complete dominance (marked vs. unmarked) or more probably with incomplete dominance in which the heterozygous individuals can be separated from the homozygous dominants by careful examination, then the chi square test shows no evidence that observed ratios are significantly different from the expected Mendelian ratios, except in three F_1 crosses of unmarked clams where a few marked individuals were found at the end of one year (Table 1).

Selective Breeding

The second phase of these studies was an attempt to demonstrate the feasibility of developing a fast-growing race of clams through selective breeding. The original plan involved rearing the fastest and the slowest growing offspring from a single pair of clams. Hereditary influence on growth would then be determined by comparing the rate of growth of offspring from each group. However, the slow-growing clams did not respond to spawning stimuli and parents from wild stock had to be substituted.

The experiments were begun by crossing one female hard clam with one male and rearing the surviving offspring. In several instances individual clams grew well during the first growing season and then poorly or not at all the second season. Undoubtedly, some variation in the rate of growth was caused by environmental factors, even though clams were reared under as nearly identical environmental conditions as possible.

At the age of 28 months these clams ranged from 14.5 to 42.0 mm in length. Of these, the 120 largest clams were selected as brood stock. When these clams were about 44 months old a large male was crossed with a large female. At the same time, one female and 2 male clams, chosen randomly from wild stock, were spawned and their larvae reared as controls.

Soon after setting it became apparent that the selectively-bred clams were growing more rapidly than the controls.

At the age of 10 weeks approximately 10,000 control clams had a total volume of 8.6 cc, while 10,000 selectively-bred clams were about 70 per cent larger with a total volume of 14 cc. When the clams were about 15 months old the total volume of 200 randomly-selected control clams was 53 cc, while the total volume of 200 randomly-selected selectively-bred clams was 86 cc or, roughly, 60 per cent greater (Fig. 2).

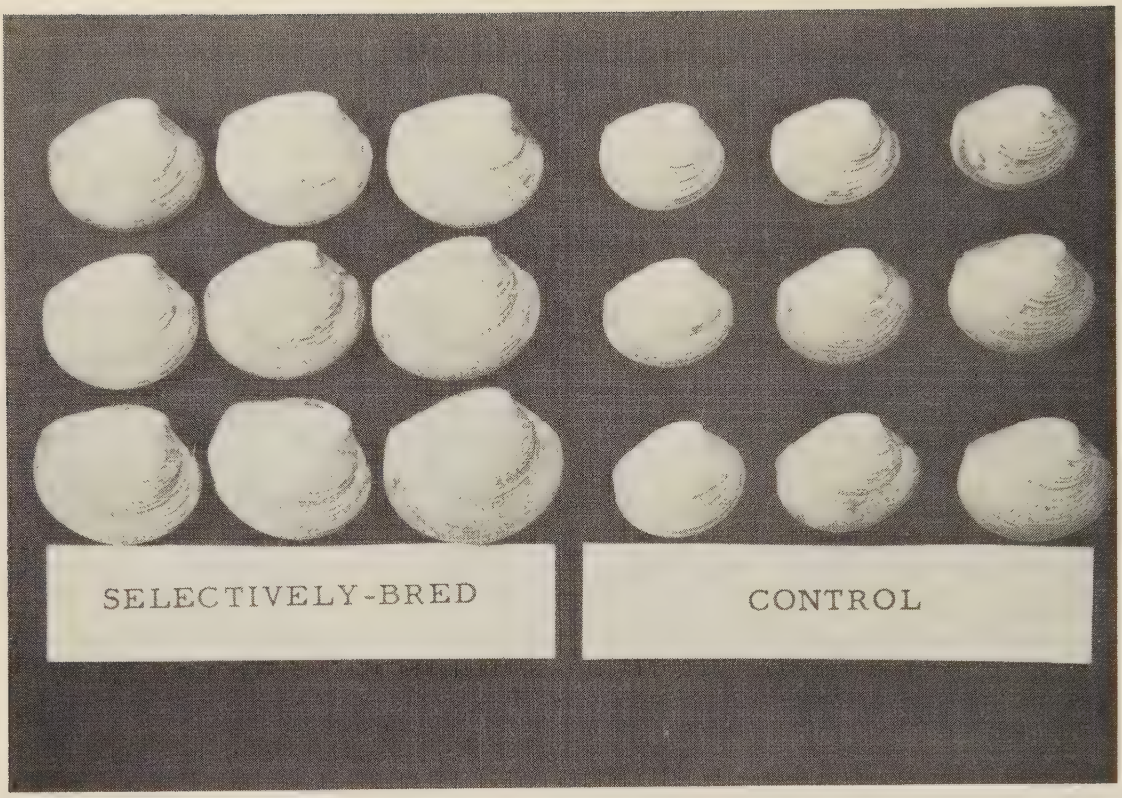


Fig. 2. Fifteen-month-old V. mercenaria, showing the largest clams from a group of selectively-bred clams compared with the largest clams from a group of clams that were not selectively bred.

At 15 months the selectively-bred clams ranged in length from 5.5 to 23.0 mm, while the control clams ranged from 6.6 to 19.0 mm. The average length of the selectively-bred clams was 13.2 mm, or 11.3 per cent greater than the average length of the controls, which was 11.8 mm.

Further selective breeding should result in even more rapid average growth of progeny, as the selection of brood stock becomes more stringent. These studies suggest that a rapid-growing strain of clams could be developed in only a few generations since in one generation of selective breeding, clams attained a 60 per cent larger size in 15 months than control clams.

ACKNOWLEDGMENTS

The author expresses his gratitude to Mr. Spofford Woodruff for his assistance with this work and to Dr. V. L. Loosanoff and Mr. H. C. Davis for their valuable advice and assistance in all phases of these experiments, from counting and measuring clams to the critical review of this report.

LITERATURE CITED

Abbott, R. Tucker, 1954. American seashells. Van Nostrand, New York. 541 pp.

Bouchon-Brandely, G. 1883. Report relative to the generation and artificial fecundation of oysters, addressed to the Minister of the Marine and the Colonies. Bull. U. S. Fish Comm. 2: 319-338.

Chanley, P. E. 1955. Possible causes of growth variations in clam larvae. Proc. Natl. Shellfish. Assoc. 45 (1954): 84-94.

Chestnut, A. F., W. E. Fahy and H. J. Porter. 1957. Growth of young Venus mercenaria, Venus campechiensis, and their hybrids. Proc. Natl. Shellfish. Assoc. 47 (1956): 50-56.

Davis, H. C. 1950. On interspecific hybridization in Ostrea. Science 111:522.

________________. 1955. Mortality of Olympia oysters at low temperatures. Biol. Bull. 109: 404-406.

Haven, D. and J. D. Andrews. 1957. Survival and growth of Venus mercenaria, Venus campechiensis, and their hybrids in suspended trays and on natural bottoms. Proc. Natl. Shellfish. Assoc. 47 (1956): 43-49.

Miner, Roy W. 1950. Field book of seashore life. Putnam, New York. 888 pp.

Morris, Percy A. 1956. A field guide to the shells of our Atlantic and Gulf coasts. 3d ed. Houghton Mifflin, Boston. 236 pp.

DEPT. OF THE INTERIOR
FISH AND WILDLIFE SERVICE
RECEIVED
JUL 19 1961
RECORDS AND
COMMUNICATIONS

Made in the United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 1, January, 1961
pp. 13-20

Atlantic Coast Migration of Large Striped Bass as Evidenced by Fisheries and Tagging

ROBERT B. CHAPOTON AND JAMES E. SYKES
U. S. Bureau of Commercial Fisheries
Beaufort, North Carolina

ABSTRACT

During studies of Atlantic coast striped bass, *Roccus saxatilis* (Walbaum), by the U. S. Fish and Wildlife Service and co-operators from 1955 to 1959, 478 large fish ranging in weight from 6 to 54 pounds and in age from 3 to 18 years were tagged. Tagging locations were the North Carolina coast, where 81 fish were tagged; Albemarle Sound and Roanoke River, North Carolina, where 97 fish were tagged; and Chesapeake Bay and tributaries, where 300 tags were applied. Catches by commercial and sport fisheries indicated that large striped bass concentrated on the coast of North Carolina in late fall and winter, on or near spawning areas for striped bass in North Carolina and Chesapeake Bay in late winter and spring, and along the coast north of Chesapeake Bay as far as Massachusetts in the summer and fall. Recaptures were made of 19 fish tagged on the North Carolina coast; 23 tagged in Albemarle Sound and the Roanoke River, North Carolina; 27 tagged in Chesapeake Bay and its tributaries; and 1 tagged in the Thames River, Connecticut. Some fish were recaptured near the tagging location but most of them migrated along the coast and were caught in other concentration areas during the season of greatest fishing pressure.

INTRODUCTION

In 1955 the U. S. Fish and Wildlife Service began a study which was concerned primarily with the effect of pollution, dams, and fishing pressure upon population size and spawning potential of striped bass, *Roccus saxatilis* (Walbaum). Investigations were first centered in North Carolina and then extended to Chesapeake Bay in 1957 in co-operation with the States of Maryland and Virginia (Sykes, 1958).

One phase of the research was designed to determine the extent of movement of large striped bass prior to and following their appearance among populations of smaller fish of the same species in sound and bay systems along the Atlantic coast. Fish 6 pounds in weight and heavier were considered large. These usually occur in small numbers in commercial catches and display migratory habits which have not been adequately delineated.

Tagging of some large individuals was reported by Merriman (1941); Vladykov and Wallace (1952); and Raney, Woolcott, and Mehring (1954). These studies resulted either in no recaptures or in recovery of the tagged fish near the site of release after a short period of time. Migration studies of large striped bass in Oregon (Morgan and Gerlach, 1950) and in California (Calhoun, 1952) show pre- and post-spawning movements within the rivers and bays, but no oceanic migration is indicated.

The present report describes migratory habits of large striped bass as determined by recent tagging programs and examination of fisheries in North Carolina, Chesapeake Bay and its tributaries, and in Connecticut. The North Carolina coastal fishery is unique in that it is entirely dependent upon the capture of large striped bass which are concentrated by area and by season each year when virtually no other species are landed. This fishery is therefore treated in greater detail than those in other areas.

FISHERIES CATCHING LARGE STRIPED BASS

North Carolina

The only known commercial fishery now being operated exclusively for catching large striped bass on the entire Atlantic coast is a haul-seine fishery in North Carolina. It is centered on the outer banks between Kitty Hawk and Cape Hatteras, a distance of approximately 50 miles, and is active during the late fall and winter months. Fish landed by the seines are known in this area as "jumbo rock." The seines currently being used vary in dimension, but generally are 5 to 7 yards deep and 425 yards long. Size of mesh (stretched) varies from 6 to 8 inches at the end of the seine and 2 to 3 inches in the center.

The first known reference to the striped bass fishery on the outer banks was by Worth (1889). He reported a single catch made by haul seine in 1887 consisting of 4,000 pounds of striped bass ranging in weight from 5 to 60 pounds. Although catch records are not available for the years prior to 1956, this reference and recent interviews with fishermen of the

TABLE 1.—*Monthly catches (pounds) of large striped bass landed on the North Carolina coast and in Albemarle Sound for seasons 1956–57 through 1958–59*[1]

Month	Season					
	1956–57		1957–58		1958–59	
	Albemarle Sound	North Carolina coast	Albemarle Sound	North Carolina coast	Albemarle Sound	North Carolina coast
September	56	–	–	–	–	–
October	13	–	–	–	–	1,000
November	22	23,000	9	–	9	3,000
December	17	111,000	16	5,000	221	51,000
January	250	14,000	227	10,000	360	20,000
February	155	6,000	145	14,000	30	60,000
March	61	3,000	149	–	114	15,000
April	114	–	–	–	190	–
Total pounds	688	157,000	546	29,000	924	150,000

[1] Unpublished catch data, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Beaufort, North Carolina. Coastal catches were reported by fishermen to the nearest thousand pounds.

area indicate that this fishery has probably operated since 1887.

Catch records of the North Carolina coastal fishery were obtained for the fishing seasons 1956–57, 1957–58, and 1958–59. Of the three seasons, the first and third produced approximately equal catches of striped bass, while the 1957–58 production was comparatively low (Table 1). Wind and high seas limited passage of fishing boats through the surf during most of this season. A minimum of five and a maximum of ten seines were known to operate during the 3 years of observation, and the period of fishing extended from late November until early March.

In addition to the coastal landings, large striped bass are taken in small quantity in the fisheries of Albemarle Sound and the Roanoke River, North Carolina. Goode (1903) stated that numerous catches were made in the western end of Albemarle Sound in 1844. He further reported that in 1876 one seine haul took 820 striped bass weighing 37,000 pounds. Of this catch, 365 fish averaged 65 pounds per fish, and a few individuals weighed 90 pounds. Smith (1907) reported that large individuals were caught in the eastern end of the sound in 1891. Presumably small striped bass were also caught during these hauls, since a resident population of fish which are predominantly small presently inhabits the sound.

Examination of commercial striped bass catches in Albemarle Sound in the years 1956 through 1958 has shown that few large fish are caught there now. The few that were taken (Table 1) were caught by anchor gill nets, haul seines, pound nets, and purse nets. These types of gear are fished for small striped bass and American shad (*Alosa sapidissima*) and are distributed throughout the sound. Catches on the coast and in Albemarle Sound are landed in approximately the same season. Oregon Inlet, a cut in the outer banks between the Atlantic Ocean and Albemarle Sound, provides a passageway through which fish may move between the two fishing grounds.

The Roanoke River, a tributary of Albemarle Sound, is the principal striped bass spawning area in North Carolina. Worth (1884, 1910) stated that many large fish were caught and stripped of ova in that river during early attempts at artificial propagation, but few are now taken in the spawning run (Dickson, 1958). There is no other known area in North Carolina where many of them are found in the spawning run, so no shift from one location to another is in evidence. Several striped bass weighing from 20 to 40 pounds have been reported in the Roanoke River in recent years, but a majority of them have weighed less than 6 pounds. Sykes and Lewis showed that spawning in the Roanoke River occurs primarily in late April and in May.[1]

Chesapeake Bay

It was not possible to separate catches of large fish from the total striped bass catch in Chesapeake Bay because there is no separate large-fish fishery, and fish sizes in commercial catches were not obtained during this study. Some large fish were known to be present, however, particularly in spring during the spawning season. Spawning in Chesapeake Bay tributaries occurs from April through

---

[1] Sykes, James E., and Robert M. Lewis. Manuscript. Striped bass spawning populations in relation to changing environmental factors in Roanoke River, North Carolina.

TABLE 2.—*Weight (pounds) and length (inches) of 265 large striped bass from North Carolina coast, Albemarle Sound, and the Roanoke River, and 303 large striped bass from Chesapeake Bay and the Potomac River*

Location and year	Number of fish	Weight		Fork length	
		Range	Mean	Range	Mean
North Carolina					
1955					
Coast	81	21.0–52.0	37.0	31.0–47.5	41.8
Albemarle Sound	3	6.0– 8.5	6.8	21.9–25.8	23.9
1956					
Coast	22	*6.0–40.0	*27.0	21.5–45.0	37.4
Albemarle Sound	4	6.5– 7.9	7.4	23.3–24.9	24.1
Roanoke River	27	6.0–18.5	8.9	21.5–32.0	24.9
1957					
Coast	2	**	**	41.0–45.0	43.0
Albemarle Sound	6	6.1–12.5	8.6	22.7–28.1	25.0
Roanoke River	19	6.0–14.2	8.4	20.4–29.2	24.0
1958					
Coast	63	12.2–50.0	32.4	30.8–48.8	39.9
Albemarle Sound	21	6.2–16.2	8.4	20.2–31.6	24.6
Roanoke River	17	6.2–10.0	7.4	20.3–24.6	22.6
Chesapeake Bay area					
1957					
Chesapeake Bay	112	6.0–44.0	12.6	21.0–44.0	29.6
1958					
Chesapeake Bay	9	7.0–51.6	26.6	25.0–46.6	35.3
1959					
Chesapeake Bay	28	†	†	21.0–50.0	30.2
Potomac River	154	6.0–57.0	16.2	21.7–46.6	30.1

*Estimated
**No range; each of two fish estimated at 35 pounds
†Only one fish weighed (16.5 pounds)

June (Massmann *et al.*;[2] Pearson, 1938; Tresselt, 1952). Recent studies have indicated that most spawning in the Potomac River in 1959 was completed by May 15.

North of Chesapeake Bay

Commercial striped bass fishing is illegal in all states north of Chesapeake Bay with the exception of Delaware, New York, and Rhode Island. There are sport fisheries in several states, and the principal areas where the large striped bass are caught are on the ocean shores of the states. The most productive areas on the basis of hook-and-line catches are: Barnegat Bay and Sandy Hook, New Jersey; Montauk Point, New York; Block Island, Narragansett, Watch Hill, and Newport, Rhode Island; and Cuttyhunk, Nantucket, and Cape Cod, Massachusetts (Fitzpatrick and Cookson;[3] Lyman and Woolner, 1954). In some of these states sport catches can be marketed. Casting and trolling are both practiced in the coastal sport fishery, which is usually active from early July through late October.

MATERIALS AND METHODS

Four types of tags were used to mark the fish in this study. Petersen disk tags with nickel pins were used on the fish tagged on the North Carolina coast. Petersen disk, nylon streamer, and soft and hard spaghetti tags were used in Albemarle Sound and in the Roanoke River (Davis, 1959). In the Chesapeake Bay area, Petersen disk, nylon streamer, and jaw ring tags were used. The jaw ring, or split ring and plate tag, was designed and described by Vladykov (1956). A return address and serial number were printed on each tag, and a reward was paid for the tag return.

Scales were collected and fork length and weight were recorded from portions of commercial landings and from most of the fish which were tagged. Weights of some fish tagged on the North Carolina coast in 1956 and 1957 were estimated. To check the accuracy of the estimates, they were plotted on the empirical length-weight curve of North Carolina fish from which complete data were obtained. Comparison showed estimated weights to be within the observed ranges for fish of similar lengths.

Large fish on North Carolina beaches were immobilized for marking by having one operator hold the tail down while another straddled the head region and faced the tail

---

[2] Massmann, William H., Ernest C. Ladd, and Henry N. McCutcheon. (1952) A biological survey of the Rappahannock River, Virginia, Part 1. Virginia Fish. Lab., Gloucester Point, 112 pp. (Mimeo.)

[3] Summaries of reports on striped bass investigations for 1956 and 1957. Commonwealth of Massachusetts, Dingell-Johnson Proj. F4R. (Mimeo.)

Table 3.—*Age of 414 large striped bass from commercial catches in North Carolina and the Potomac River*

Age group	North Carolina coast				Albemarle Sound				Roanoke River			Potomac River	Total
	1955	1956	1957	1958	1955	1956	1957	1958	1956	1957	1958	1959	
III	—	—	—	—	1	—	—	1	1	2	1	18	24
IV	—	1	—	—	1	—	1	4	2	6	8	25	48
V	—	—	—	2	—	2	1	5	13	4	4	14	45
VI	—	2	—	2	1	—	3	7	7	2	4	25	53
VII	1	2	—	13	—	—	—	2	—	—	—	28	46
VIII	3	4	—	6	—	1	1	—	2	2	—	22	41
IX	4	2	—	6	—	—	—	—	1	—	—	10	23
X	3	1	—	6	—	—	—	—	—	—	—	6	16
XI	5	4	—	4	—	—	—	—	—	—	—	3	16
XII	3	2	1	8	—	—	—	—	—	—	—	3	17
XIII	11	—	1	5	—	—	—	—	—	—	—	1	18
XIV	14	2	—	6	—	—	—	—	—	—	—	5	27
XV	16	1	—	3	—	—	—	—	—	—	—	2	22
XVI	7	—	—	2	—	—	—	—	—	—	—	2	11
XVII	5	—	—	—	—	—	—	—	—	—	—	—	5
XVIII	1	—	—	—	—	—	—	—	—	—	—	1	2
Number	73	21	2	63	3	3	6	19	26	16	17	165	414
Average age	13.4	9.6	12.5	10.2	4.3	6.0	5.8	5.3	5.5	4.9	4.6	6.8	8.3

to attach the tag. Scales were taken and length was measured while the fish was lying on the beach. For determination of weight, the fish was pushed head first into a large plastic bucket which was then suspended from scales mounted on a tripod. Immediately after weighing, the fish was carried in the bucket to the water.

In Chesapeake Bay and tributaries fish were tagged and scales, length, and weight obtained as they were taken from nets into commercial fishing boats. Tagging was done in the manner previously described, but was slightly more difficult because deck space was limited.

Twenty-two large striped bass were tagged in the vicinity of Oregon Inlet, North Carolina, in December 1956, and 57 were tagged there in December 1958. Because fishing success was relatively poor there in the 1957–58 season, few fish were observed and only two were tagged.

From 1955 through 1958, 4,361 striped bass of all sizes were tagged from commercial fishing gear in Albemarle Sound, North Carolina. Of these, 34 fish were in the large category and were tagged from late October through March. From 1956 through 1958, 856 fish of all sizes including 63 large fish were tagged from commercial gear in the Roanoke River, North Carolina. The period of tagging extended from April through early July.

During the cooperative study between the States of Maryland and Virginia, and the U. S. Bureau of Commercial Fisheries, 7,254 fish were tagged in Chesapeake Bay and tributaries from 1957 through 1959, and of these 149 were large fish. Areas of tagging in Virginia were the York, James, and Rappahannock Rivers; and in Maryland, the Nanticoke and Elk Rivers, the Chesapeake and Delaware Canal, and Spesutie Island, Swan Point Bar and in the vicinity of the Little Choptank River.[4] In addition to this tagging in the Chesapeake Bay system, 2,197 striped bass of all sizes taken by commercial gear were tagged in the Potomac River from January to May, 1959. Of these, 92 were large fish.

In the spring and summer of 1956, 131 striped bass of all sizes were tagged in the Thames River, Connecticut, by the Connecticut State Board of Fisheries and Game. Weights at the time of tagging are unknown except for one large fish.

In addition to those fish tagged, large striped bass landed by beach seines and other commercial fishing gear were occasionally examined. In December 1955 and December 1958, a total of 87 large striped bass was examined on the North Carolina coast and length, weight, and scales were obtained for the purpose of supplementing data from tagged fish. In 1959, 62 large fish were examined from catches in the Potomac River.

Ages were determined from plastic impressions of scales which were removed from the left side of the body midway between the two dorsal fins and the lateral line. Usually 8 to

---

[4] Information regarding these fish and some tagged in the Chesapeake Bay area in 1955 and 1956 prior to the co-operative study was supplied through the courtesy of Maryland Department of Research and Education, Maryland Department of Tidewater Fisheries, D-J Project F3R—Rockfish Investigations, and Virginia Fisheries Laboratory.

TABLE 4.—*Summary of 19 striped bass tagged in 1956 and 1958 on the North Carolina coast and recaptured*

Date of tagging	Number tagged	Location of recovery							
		Near tagging site		Albemarle Sound[1]		Chesapeake Bay[1]		On coast north of bay[2]	
		Number	Weight	Number	Weight	Number	Weight	Number	Weight
December 3–19, 1956	22	—	—	2	25.0[3] 6.0	2	40.0[3] 30.0[3]	2	25.0[3] 10.0[3]
December 2–23, 1958	57	5	29.2 19.5 17.8 17.8 17.2	—	—	6	49.5 34.2 32.8 30.2 29.1 18.2	2	33.0 27.2
Total	79	5	—	2	—	8	—	4	—

[1] Prior to and during spawning
[2] After spawning
[3] Estimated weight

12 scales were obtained from each fish. The scale impressions were viewed with an Eberbach scale projector and a dissecting microscope, and age assigned from the number of completed annuli. Two biologists read the scales independently and in cases of disagreement, the scales were re-examined jointly. The first joint reading produced agreement in about two-thirds of the cases.

Ranges and means in weight and fork length were obtained from 568 large striped bass tagged and examined in North Carolina and in the Chesapeake Bay area from 1955 to 1959 (Table 2). Age frequency of 414 North Carolina and Potomac River fish is shown in Table 3.

TAG RECOVERIES

Of the 79 large fish tagged on the North Carolina coast in 1956 and 1958, recoveries were made in four separate fishing areas: five fish within 10 days after release near the point of tagging; two in Albemarle Sound prior to or during the spawning season; eight in the Chesapeake Bay system prior to and during the spawning season; and four on the Atlantic coast after the spawning season (Figure 1). One of these four fish was taken off Sandy Hook, New Jersey, on June 16; one at Elberon, New Jersey, on August 5; one off Watch Hill, Rhode Island, on July 15; and one at Provincetown, Massachusetts, on September 27 (Table 4). Neither of the two fish tagged in 1957 was recaptured.

Of the 34 large striped bass tagged in Albemarle Sound in 1955, 1956, 1957, and 1958, one was recovered at Dennis, Massachusetts, on July 8, 1956; 12 in the sound during commercial fishing seasons; and one in the Roanoke River in May (Table 5).

Of the 63 large fish tagged in the Roanoke River during the spawning runs of 1956, 1957, and 1958, one was recovered near the tagging site in the season of tagging and eight in Albemarle Sound during commercial fishing seasons of the next 2 years (Table 5).

Of the fish tagged in the Chesapeake Bay area, 14 recoveries were made from the 92 large fish tagged on and near the spawning

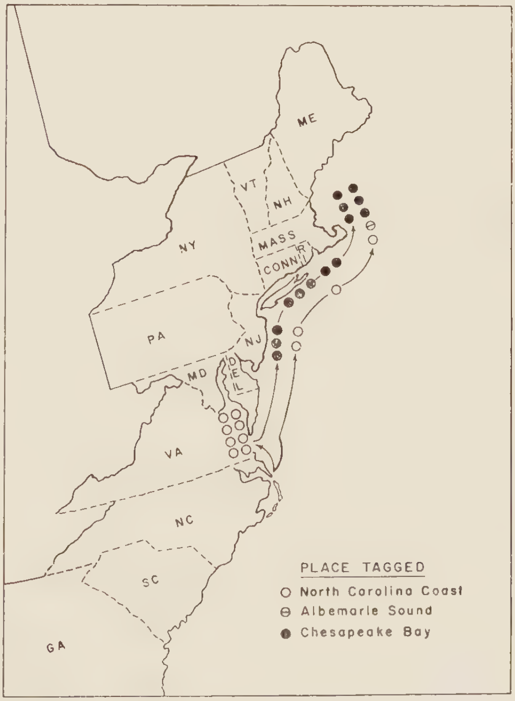


FIGURE 1.—Recovery points of fish tagged on the coast of North Carolina; in Albemarle Sound, North Carolina; and in Chesapeake Bay.

TABLE 5.—*Summary of 23 striped bass tagged in Albemarle Sound and in the Roanoke River, North Carolina, 1955–58, and recaptured*

Date and place of tagging	Number tagged	Location of recovery							
		Near tagging site		Albemarle Sound[1]		Roanoke River[1]		On coast north of bay[2]	
		Number	Weight	Number	Weight	Number	Weight	Number	Weight
Albemarle Sound									
November 22–28, 1955	3	—	—	—	—	—	—	1	8.5
November 13—December 10, 1956	4	1	6.5	—	—	1	7.6	—	—
February 25–27, 1957	5	—	—	4	9.0 7.8 7.6 6.1	—	—	—	—
October 29, 1957	1	—	—	1	8.5	—	—	—	—
January 15—March 24, 1958	21	3	10.8 7.4 6.2	3	16.2 10.1 8.2	—	—	—	—
Roanoke River									
April 19—July 2, 1956	27	—	—	6	17.0 9.0 7.0 6.3 6.2 6.0	—	—	—	—
April 1—May 14, 1957	19	1	8.3	1	6.5	—	—	—	—
April 30—May 9, 1958	17	—	—	1	6.2	—	—	—	—
Total	97	5	—	16	—	1	—	1	—

[1]Prior to or during spawning
[2]After spawning

grounds of the Potomac River in 1959 (Table 6). Four of these fish were recovered in the Potomac River and eight in Chesapeake Bay during the spring and summer of 1959. Two fish were caught on the coast north of the bay subsequent to the spawning season; one at Cuttyhunk, Massachusetts, on June 10, and the other at Montauk, New York, on October 17.

The 13 returns from fish tagged in other areas of Chesapeake Bay were made after the spawning season. Recovery of 12 of these fish was made along the Atlantic coast north of the bay (Figure 1) from June through October, and one fish was recovered south of the bay on the North Carolina coast in December. Some recoveries referred to have been listed previously by Mansueti (1958), by Hollis for the Maryland Board of Natural Resources (1955, 1956, 1957, and 1958), and by Hollis and Davis.[5] These include the recovery of fish tagged in the Nanticoke River, in the Chesapeake and Delaware Canal, and at Spesutie Island (Table 6).

One fish which was tagged in the Thames River, Connecticut, in June 1956 was recaptured in December 1959, 891 days later, on the North Carolina coast. This was the only fish recovered in North Carolina of the 131 fish tagged in Connecticut. Twenty-six recoveries were made either in the Thames River or nearby water systems in the next 3 years. An additional three fish were recovered along the Atlantic coast south of the tagging site; one off New Jersey and two in Chesapeake Bay. Weights of the recaptured fish are unknown except for the fish recovered in North Carolina.

DISCUSSION AND CONCLUSIONS

It is apparent from the present study and those made by Merriman (1941), Raney (1952), and Vladykov and Wallace (1952) that two primary size groups of striped bass exist in fisheries of the Atlantic coast; one occurring prominently in the 2- to 3-pound class, and the other in the 30- to 40-pound class. The smaller group ranges in weight from 1 to 6 pounds and the larger from 6 pounds to approximately 75 pounds. The latter group, which comprises a small portion of the total catch, represents the small percentage of fish which escape natural and fishing mortality for several years. Fishing mortality appears to be particularly high during the first 3 years of life.

The separation of the two groups is most apparent in North Carolina, where in December both a geographical and a size difference

---

[5] Hollis, Edgar H., and Harold A. Davis, Jr. (1955) Report of striped bass studies in Maryland. Atlantic States Marine Fish. Comm., Chesapeake Bay Sect., 14th Ann. Meeting, Virginia Beach, Va., Appendix CB. (Mimeo.)

TABLE 6.—*Summary of 27 recaptured striped bass tagged in Chesapeake Bay area*

Place of tagging	Date of tagging	Number tagged	Location of recovery					
			Near tagging site (within bay system)		On coast north of bay after spawning		On coast south of bay after spawning	
			Number	Weight	Number	Weight	Number	Weight
Nanticoke River, Maryland	April 22, 1955	4	—	—	1	27.0	—	—
	May 9–10, 1956	15	—	—	1	15.0[1]	—	—
	April 19–29, 1958	2	—	—	2	48.0 16.0	—	—
	April 9, 1959	5	—	—	1	20.0[1]	—	—
Spesutie Island, Maryland	May 10, 1956	34	—	—	3	25.0[1] 24.0[1] 22.5[1]	—	—
Chesapeake and Delaware Canal, Maryland	April 26–30, 1957	16	—	—	1	6.5	1	45.0[2]
Potomac River, Maryland	January 24—May 4, 1959	92	12	17.2 16.0 15.2 15.0 14.9 14.8 13.6 13.5 12.3 12.0 11.9 8.8	2	28.5 21.5	—	—
York River, Virginia	February 27, 1957	37	—	—	2	11.2 8.6	—	—
	February 25, 1958	1	—	—	1	7.5	—	—
Total		206	12	—	14	—	1	—

[1] Weight determined at time of recovery

[2] Estimated weight at tagging

are clearly illustrated. On the Albemarle Sound side of the outer banks there is an extensive, resident population of the small size group, while on the ocean side fish in the large size group are concentrated. Most fish from the coastal catches weighed 6 pounds or more, and the population was distinct from all others on the basis of fish size and location of the group in the season of observation.

The recovery of large striped bass tagged in the North Carolina coastal fishery, which is specifically for large fish, showed that this fishery is seasonal, because large fish are present for only short periods during their extensive coastal movements. Fish tagged on the coast of North Carolina in two fishing seasons were recovered in the commercial fisheries of North Carolina or Chesapeake Bay prior to or during the spawning period or by sport fisheries on the coast north of Chesapeake Bay after the spawning season. Some of the spring recoveries were made directly on or near the spawning grounds of Chesapeake Bay and Albemarle Sound tributaries. These recoveries link the North Carolina fish with large striped bass that are taken occasionally on known spawning grounds of Chesapeake Bay and Albemarle Sound. Fish tagged in Albemarle Sound and in the Roanoke River over a 4-year period were recovered either in the commercial fisheries of the sound or river or in the sport fisheries north of Chesapeake Bay after the spawning season.

The combined tag returns from all areas show a continuation of what is believed to be a seasonal migratory cycle similar to that of the American shad (Talbot and Sykes, 1958). Tags applied to striped bass in the bay and tributaries over a 5-year period were recovered from the bay or from the Middle Atlantic and New England coasts in the summer and fall and on the coast of North Carolina in late fall and winter.

The fact that some fish tagged in the Potomac River were recovered in Chesapeake Bay as late as September shows that all of the large fish do not leave the bay immediately after the spawning season. Fish tagged in Albemarle Sound and in the Roanoke River over a 4-year period were recovered as late as October in the sound and did not all leave it immediately after the spawning season. A few large striped bass are taken at all seasons of the year in Albemarle Sound and Chesapeake Bay, but these fish appear in largest number at the times and in the places of major tag recoveries. Movement from New England south to North Carolina needs further verification even though a complete migratory cycle is suggested.

This study of movement of large striped bass between states helps in clarifying one element of the life history of this species and presents problems differing from those encountered in management of the more restricted estuarine populations. It is apparent that the large fish are subject to exploitation in three widely separated geographical areas each year. With this knowledge available, further study of management problems will be facilitated.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the aid given by William H. Massmann of Virginia Fisheries Laboratory, Romeo J. Mansueti of the Maryland Department of Research and Education, and Edgar H. Hollis of the Maryland Department of Tidewater Fisheries, in supplying tag-return information and in critical review of the manuscript. Appreciation is also expressed to the personnel of the Connecticut State Board of Fisheries and Game for supplying tagging information.

LITERATURE CITED

Calhoun, A. J. 1952. Annual migrations of California striped bass. Calif. Fish and Game, 38 (3): 391–403.

Davis, William S. 1959. Field tests of Petersen, streamer, and spaghetti tags on striped bass, *Roccus saxatilis* (Walbaum). Trans. Am. Fish. Soc., 88: 319–329.

Dickson, Arthur W. 1958. The status of striped bass (*Roccus saxatilis*) (Walbaum) in North Carolina waters. Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm., 11: 264–268.

Goode, G. Brown. 1903. American fishes. Rev. ed. D. Estes and Co., Boston. 562 pp.

Lyman, Henry, and Frank Woolner. 1954. The complete book of striped bass fishing. A. S. Barnes and Co., New York. 242 pp.

Mansueti, Romeo J. 1958. Striped bass tagged by Solomons Laboratory remain largely in bay. Maryland Tidewater News, 14 (6): 22, 24.

Maryland Board of Natural Resources. 1955. Ann. Rept., 12: 39–43.

———. 1956. Ann. Rept., 13: 39–41.

———. 1957. Ann. Rept., 14: 35–38.

———. 1958. Ann. Rept., 15: 31–34.

Merriman, Daniel. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic coast. Fish. Bull., U. S. Fish and Wildl. Serv., 50: 1-77.

Morgan, Alfred R., and Arthur R. Gerlach. 1950. Striped bass studies on Coos Bay, Oregon in 1949 and 1950. Oregon Fish Comm., Contr. 14, 31 pp.

Pearson, John C. 1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). Bull. U. S. Bur. Fish., 49: 825–851.

Raney, Edward C. 1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull. Bingham Oceanogr. Coll., 14 (1): 5–97.

Raney, Edward C., William S. Woolcott, and Albert G. Mehring. 1954. Migratory pattern and racial structure of Atlantic coast striped bass. Trans. N. Am. Wildl. Conf., 19: 376–396.

Smith, Hugh M. 1907. The fishes of North Carolina. North Carolina Geol. and Econ. Survey, Rept. 2, 453 pp.

Sykes, James E. 1958. Problems relative to the Atlantic coast striped bass fishery and status of its biological research. Trans. N. Am. Wildl. Conf., 23: 370–377.

Talbot, G. B., and James E. Sykes. 1958. Atlantic coast migrations of American shad. Bull. U. S. Bur. Fish., 58: 473–490.

Tresselt, Ernest F. 1952. Spawning grounds of the striped bass or rock, *Roccus saxatilis* (Walbaum), in Virginia. Bull. Bingham Oceanogr. Coll., 14 (1): 98–110.

Vladykov, Vadim D. 1956. Fish tags and tagging in Quebec waters. Trans. Am. Fish. Soc., 86: 345–349.

Vladykov, Vadim D., and David H. Wallace. 1952. Studies of the striped bass, *Roccus saxatilis* (Walbaum), with special reference to the Chesapeake Bay region during 1936–1938. Bull. Bingham Oceanogr. Coll., 14 (1): 132–177.

Worth, S. G. 1884. Report upon the propagation of striped bass at Weldon, N. C. in the spring of 1884. Bull. U. S. Fish Comm., 4: 225–230.

———. 1889. The striped bass or rockfish industry of Roanoke Island, North Carolina, and vicinity. Bull. U. S. Fish Comm., 7: 193–197.

———. 1910. Progress in hatching striped bass. Trans. Am. Fish. Soc., 39: 155–159.

Reprint from:

20

GALATHEA REPORT

Volume 5

Scientific Results
of The Danish Deep-Sea Expedition
Round the World 1950-52

ISSUED BY THE GALATHEA COMMITTEE
PRESIDENT: H.R.H. PRINCE AXEL OF DENMARK

Daniel M. Cohen:

ON THE IDENTITY OF THE SPECIES OF THE FISH GENUS *ARGENTINA* IN THE INDIAN OCEAN

DANISH SCIENCE PRESS, LTD.
COPENHAGEN
1961

GALATHEA REPORTS

VOLUME 1

Bruun, Anton F.: General Introduction to the Reports and List of Deep-Sea Stations. 42 pp., 11 text-figs, 4 pls.
Nielsen, E. Steemann & E. Aabye Jensen: Primary Oceanic Production. The Autotrophic Production of Organic Matter in the Oceans. 88 pp., 41 text-figs.
Braarud, Trygve: A Red Water Organism from Walvis Bay. 2 pp., 2 text-figs.
ZoBell, Claude E. & Richard Y. Morita: Deep-Sea Bacteria. 16 pp., 4 text-figs.
Kiilerich, A.: Bathymetric Features of the Philippine Trench. 17 pp., 12 text-figs., 4 pls.
Kramp, P. L.: *Stephanoscyphus* (Scyphozoa). 15 pp., 12 text-figs., 1 pl.
Millar, R. H.: Ascidiacea. 21 pp., 20 text-figs., 1 pl.
Dahl, Erik: Amphipoda from Depths Exceeding 6000 Meters. 31 pp., 20 text-figs.
Pickford, Grace E.: Vampyromorpha. 11 pp., 1 text-fig.
Rofen, Robert R.: The Whale-Fishes: Families Cetomimidae, Barbourisiidae and Rondeletiidae (Order Cetunculi). 6 pp., 4 text-figs.

VOLUME 2

Carlgreen, Oscar: Actiniaria from Depths Exceeding 6000 Meters. 7 pp., 7 text-figs., 1 pl.
Kramp, P. L.: Hydroids from Depths Exceeding 6000 Meters. 4 pp., 6 text-figs.
Madsen, F. Jensenius: *Primnoella krampi* n. sp. A New Deep-Sea Octocoral. 2 pp., 1 text-fig.
Madsen, F. Jensenius: Echinoidea, Asteroidea, and Ophiuroidea from Depths Exceeding 6000 Meters. 11 pp., 5 text-figs., 1 pl.
Hansen, Bent: Holothurioidea from Depths Exceeding 6000 Meters. 22 pp., 25 text-figs.
Hansen, Bent & F. Jensenius Madsen: On Two Bathypelagic Holothurians from the South China Sea. *Galatheathuria* n. g. *aspera* (Théel) and *Enypniastes globosa* n. sp. 5 pp., 2 text-figs., 1 pl.
Gislén, Torsten: Crinoids from Depths Exceeding 6000 Meters. 2 pp., 1 pl.
Kirkegaard, J. B.: Benthic Polychæta from Depths Exceeding 6000 Meters. 16 pp., 13 text-figs.
Kirkegaard, J. B.: Pogonophora. *Galathealinum bruuni* n. gen. n. sp., a New Representative of the Class. 5 pp., 2 text-figs.
Wolff, Torben: Isopoda from Depths Exceeding 6000 Meters. 73 pp., 56 text-figs.
Fage, Louis: Les Pycnogonides du genre *Nymphon*. 7 pp., 10 text-figs.
Fage, Louis: Les Pycnogonidés (excl. le genre *Nymphon*). 16 pp., 22 text-figs.
Kirkegaard, J. B.: Pogonophora. First Records from the Eastern Pacific. 4 pp., 4 text-figs.
Wolff, Torben: Crustacea Tanaidacea from Depths Exceeding 6000 Meters. 55 pp., 54 text-figs.
Wieser, Wolfgang: Some Free Living Marine Nematodes. 11 pp., 4 text-figs.

VOLUME 3

Lemche, Henning and Karl Georg Wingstrand: The anatomy of *Neopilina galatheae* Lemche, 1957 (Mollusca Tryblidiacea). 63 pp., 1 text-fig., 56 pls.
Schmidt, W. J.: Bemerkungen zur Schalenstruktur von *Neopilina galatheae*. 5 pp., 2 pls.
Munk, O.: The eyes of *Ipnops murrayi* Günther, 1878. 9 pp., 3 text-figs., 2 pls.

VOLUME 4

Kirkegaard, J. B.: Pogonophora III. The Genus *Lamellisabella*. 4 pp., 3 text-figs.
Wolff, Torben: Description of a Remarkable Deep-Sea Hermit Crab, with Notes on the Evolution of the Paguridea. 22 pp., 11 text-figs.
Madsen, F. Jensenius: The Porcellanasteridae. A Monographic Revision of an Abyssal Group of Sea-Stars. 142 pp., 43 text-figs., 13 pls.
Madsen, F. Jensenius: On the Zoogeography and Origin of the Abyssal Fauna, in View of the Knowledge of the Porcellanasteridae. 42 pp., 2 text-figs.
Nielsen, Jørgen: Heterosomata (Pisces). 8 pp., 3 text-figs., 1 pl.

Printed by Nordlundes Bogtrykkeri, Copenhagen

Price: 4 Danish Kroner

ON THE IDENTITY OF THE SPECIES OF THE FISH GENUS *ARGENTINA* IN THE INDIAN OCEAN

By DANIEL M. COHEN
U. S. Fish and Wildlife Service, Washington

The eastern North Atlantic and Mediterranean fish *Argentina sphyraena* has been recorded twice from the western Indian Ocean, once by Gilchrist and von Bonde (1924:33) and once by Pfaff (1956: 148). As I have previously written (Cohen 1958), the specimens of the former authors were listed but not described, and have apparently been lost. The specimens collected by the Danish research vessel "Galathea" and noted by Dr. Pfaff have, however, been made available for study through the kindness of Dr. Jørgen Nielsen, to whom I express thanks.

Although I predicted that the eastern Indian Ocean argentinid would probably be referable to the genus *Glossanodon*, I must admit error. Examination of the material taken shows that the species is quite plainly an *Argentina*, although not *A.sphyraena*. It is in fact much closer to *A.elongata*, though differing from all of the three named subspecies. As I have only two specimens and thus no idea as to the degree of variability of the taxonomic characters which I have used, it is with some trepidation that I predict the existence of a full species; however, this seems a wiser course than describing the form as a subspecies, a category which is even more dependent upon analysis of variation. Therefore I describe a species with the realization that when additional material is available re-evaluation and perhaps recognition as a subspecies will be necessary.

Argentina euchus n. sp.

Argentina sphyraena (non Linnaeus 1758) Gilchrist and von Bonde 1924, p. 3 (synonymy; St. 295, lat. 26°00′45″S., long. 33°19′50″E., 180 fms., St. 375, lat. 29°42′40″S., long. 31°39′20″E., 201 fms.). – Barnard 1925, p. 128 (brief descr. from literature). – Smith 1953, p. 96, fig. 127 (brief descr., from literature, fig. is *Argentina silus)*. – Pfaff 1956, p. 148 (off Natal).

Diagnosis. – This species can be distinguished from *A.sphyraena* and *A.silus* by its branchiostegal ray count of five rather than six; from *A.sialis* in having six gill rakers on the lower arm of the first gill arch rather than 14 to 21; from *A.striata* in having 17 pectoral rays, a low number of teeth on the palatines and vomer and 10 ventral rays, rather than 18 to 20 pectoral rays, a high number of teeth and 11 to 13 ventral rays; from *A.elongata* in having 10 ventral rays rather than 11 to 13 rays and having 48 to 49 lateral line scales rather than 51 to 54 lateral line scales. Some differences between *A.euchus* and the subspecies of *A.elongata* are summarized in table 1.

Counts and measurements (in mm.). – The holotype first followed by the paratype in parenthesis – Dorsal 11 (11); anal 12 (12); pectoral 17-17 (?-17); ventral 10-10 (10-10); gill rakers 2+1+6 (3+1+6); lateral line scale rows 48 (49); standard length 158 (146); preanal 131 (119); preventral 83.5 (76.5); predorsal 71.4 (60.2); prepectoral 46.0 (42.9); head length 45.2 (40.2); snout 16.6 (13.6); eye 14.1 (13.7); maxillary length 8.0 (7.1); maxillary width 2.8 (2.5); body depth at dorsal fin 23.4 (22.0); body width behind head 19.0 (17.0); depth of head 20.5 (20.5); least depth of caudal peduncle 9.4 (9.0); vertebrae in paratype 48.

Description. – Body elongate, almost rectangular in cross section, more strongly compressed posteriorly. Greatest depth at the origin of the dorsal fin, tapering to the caudal peduncle. The dorsal profile of the head descending in a very slight curve from the eye to the snout. The dorsal rim of the orbit projecting only very slightly, if at all, into the dorsal profile of the head. The interorbital is broad and flat between the supraocular canals, which are themselves raised slightly above the flat surface. Lateral to the canals the frontals slope down somewhat over the top of the orbit. The preorbital forms

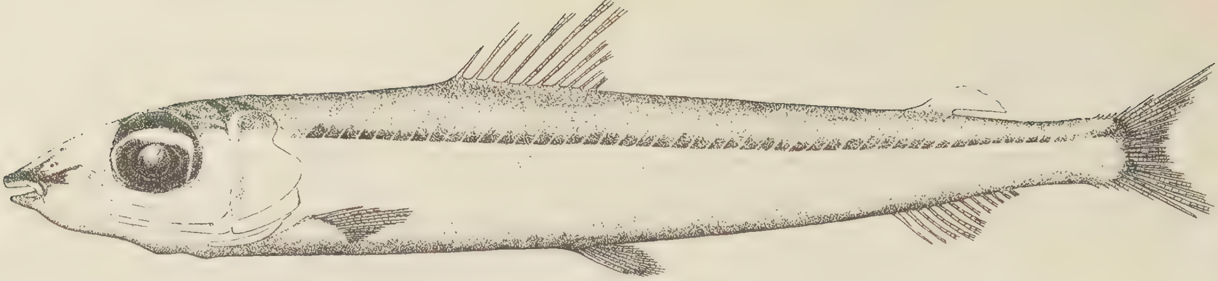


Figure 1. Paratype of *Argentina euchus* n. sp. Drawn by MIRIAM SCHAFFER.

a sheath which covers the dorsal edge of the maxillary when the mouth is closed. Sensory papillae are present on portions of the membrane covering the premaxillary. Both the upper and lower jaws are rounded when viewed ventrally. When the mouth is closed, the upper jaws project slightly. There is no knob at the symphysis of the lower jaws.

The palatines and the head of the vomer bear a continous band of small, closely spaced, posteriorly directed teeth. The band varies in width from a single tooth at the posterior ends of the palatines to as much as 5 or 6 teeth at the apex of the vomer. It is not possible to distinguish between vomerine and palatine teeth without dissection. The tongue bears 7 strong teeth. The gill rakers on the lower arm of the first arch are small, very widely spaced, roughly triangular in shape, and compressed. The base of the inner edge of each raker bears a fleshy pad. The rakers increase in size from the angle anteriorly, the largest being about as long as the maxillary is wide. The three rakers on the upper arm of the first arch are reduced to very small pointed structures.

The pectoral fin originates behind a vertical from the posterior tip of the opercles. The pectoral fin is inserted at an angle of about 40 degrees from the horizontal. The distance between the bases of the innermost pectoral rays is slightly less than the eye diameter.

The fin rays are all broken off short. Not a single scale remains on the specimens.

The ventral half of the body is light brown. An indistinct orange-brown band begins in the midline at the level of the origin of the dorsal fin and extends posteriorly, becoming wider and then almost disappearing on the caudal peduncle. The dorso-lateral part of the body is colored by dark brown chromatophores which are more densely distributed on the sides of the fish than on top. Above the lateral line the chromatophores are expanded and form a narrow but well defined dark brown line which runs the length of the fish, becoming indistinct only on the caudal peduncle, where it merges with a dark brown area along the base of the caudal fin. A single dark streak runs along the midline of the dorsum. The muzzle and the top of the skull behind the interorbital area are dark. The holotype is generally lighter than the paratype.

Holotype: A specimen 158 mm. in standard length, taken at "*Galathea*" St. 202 in the Indian Ocean, latitude 25°20′S., longitude 35°17′E., 590 m (Copenhagen University Zoological Museum No. 19519). Paratype: 146 mm. Data as for the holotype.

The name is derived from the Greek word *euchos*, the thing prayed for, and refers to the fact that this specimen is the answer to a longstanding puzzle.

Table 1. Comparisons between the holotype and paratype of *Argentina euchus* and the three subspecies of *Argentina elongata*. Measurements are expressed as percent of standard length.

Species	*A. euchus holotype*	*A. euchus paratype*	*A. elongata elongata*	*A. elongata australiae*	*A. elongata kagoshimae*
No. of examples	1	1	21	12	17
Ventral fin rays	10	10	11 (11-13)	12 (11-13)	12 (11-12)
Gill rakers on first arch	2+1+6	3+1+6	2 (1-3) +1+9 (8-10)	1 (1-2) +1+6 (6-7)	2 (0-3) +1+6 (5-6)
Lateral line scale rows	48	49	54 (51-54)	54 (51-54)	54 (51-54)
Preanal distance	82.9	81.5	82.8 (79.2-85.2)	83.8 (82.5-85.0)	85.0 (83.1-87.2)
Maxillary width	1.7	1.7	1.5 (1.3-1.6)	1.4 (1.2-1.5)	1.4 (1.2-1.5)
Body depth at dorsal fin	14.8	15.1	13.3 (11.9-15.3)	10.8 (10.1-11.5)	12.5 (10.4-14.7)
Head depth	13.0	14.0	12.1 (10.9-13.6)	11.0 (10.5-11.4)	11.1 (10.4-12.6)

LITERATURE CITED

BARNARD, K. H., 1925: A monograph of the marine fishes of South Africa. Part I. – Ann. S. Afr. Mus. **21**, 128.

COHEN, D. M., 1958: A revision of the fishes of the subfamily Argentininae. – Bull. Florida St. Mus., Biol. Sci., **3**, 3, 94-173.

GILCHRIST, J. D. F. and VON BONDE, C., 1924: Deep-sea fishes procured by the S. S. "Pickle" (Part II). Rept. no. 3 for the year 1922. Union of S. Afr. Fish. and Mar. Survey, spec. rept. 7, 1-24.

PFAFF, J. R., 1956: Coastal fish. – *In* The Galathea Deep Sea Expedition – described by members of the expedition, edit. A. BRUUN *et al.* New York, 134-148.

SMITH, J. L. B., 1953: The sea fishes of southern Africa. Rev. edit.-Capetown.

1. 11. 61. 600. 375

LIST OF PAPERS RESULTING IN WHOLE OR IN PART FROM

THE GALATHEA DEEP-SEA EXPEDITION ROUND THE WORLD 1950-52

(Supplementary to the list given in the Introduction to vol. 1, 1959, pp. 18-19).

Abbott, R. Tucker, 1958: Marine Mollusca of Rennell Island, Solomon Islands. – The Natural History of Rennell Island, British Solomon Islands, **2**: 203-206, 1 pl.

Balfour-Browne, J., 1958: Coleoptera (Pars). – Ibid.: 127-133.

Bauchot, M. L. & M. Blanc, 1961: Poissons marins de l'Est Atlantique tropical. I. Labroidei (Téléostéens Perciformes). – Atlantide Rep., **6**: 43-64, 6 text-figs.

— — 1961: Poissons marins de l'Est Atlantique tropicale. II. Percoidei (Téléostéens Perciformes). $1^{ère}$ partie. – Ibid.: 65-100, 4 text-figs., 1 pl.

Bruun, A. F.: On the Restricted Distribution of two Deep-sea Fishes, *Borophryne apogon* and *Stomias colubrinus*. – Sears Found.: Journ. Mar. Res. **17**: 103-112, 2 text-figs.

— 1960: Exploring the World's Deepest Trenches. – The Courier, UNESCO, Nos. 7-8: 20-22, 5 text-figs.

— & Torben Wolff, 1961: Abyssal Benthic Organisms: Nature, Origin, Distribution, and Influence on Sedimentation. – In: Oceanography (M. Sears ed.), Publ. No. 67 A. A. A. S., Washington: 391-397, 1 text-fig.

Buck, F. D., 1958: Cistelidae and Tenebrionidae (Coleoptera) from Rennell Island. – The Natural History of Rennell Island, British Solomon Islands, **2**: 115-119, 1 pl.

Chamberlin, Ralph V., 1958: Millipeds and Centipeds from Rennell and Guadalcanal Islands. – Ibid.: 207-212, 4 text-figs.

Clay, Theresa, 1958: Mallophaga (Insecta). Part I. – Ibid.: 143-149.

Clench, William J., 1958: The Land and Freshwater Mollusca of Rennell Island, Solomon Islands. – Ibid.: 155-202, 3 text-figs., 4 pls.

Forest, Jaques, 1961: Pagurides de l'Afrique occidentale. – Atlantide Rep., **6**: 203-250, 19 text-figs.

Haig, J., 1959: Porcellanid Crabs from West Africa. – Atlantide Rep., **5**: 327-332.

Hansen, L., 1960: Some Macromycetes from Rennell and Alcester Islands. – The Natural History of Rennell Island, British Solomon Islands, **3**: 127-132.

Hjortaa, H., 1961: "Galatheas" Wunderfisch – Galatheathauma axeli. – Der Präparator, Bonn, **7**, 1: 169-171, 2 text-figs.

Kirkegaard, J. B., 1959: The Polychaeta of West Africa. Part I. Sedentary Species. – Atlantide Rep., **5**: 7-117, 25 text-figs.

Kramp, P. L., 1959: Some New and Little-known Indo-Pacific Medusae. – Vidensk. Medd. Dansk Naturh. Foren., **121**: 223-259, 19 text-figs.

Laird, Marshall & Elisabeth Marshall, 1959: Culicidae and Haematozoa from Bellona and Rennell. – The Natural History of Rennell Island, British Solomon Islands, **2**: 213-234, 2 pls.

Lemche, H., 1959: Molluscan phylogeny in the light of *Neopilina*. – Proc. XV. Intern. Congr. Zool. London: 380-381.

— 1959: Protostomian interrelationships in the light of *Neopilina*. – Ibid.: 381-389.

— 1959: Neopilina. (Un molusco actual, con caracteres de tipo fosil, y su significado). – Revista Univ. Madrid, **8**: 411-442, 12 text-figs.

Lemche, H., 1960: A Possible Central Place for Stenothecoides Resser, 1939 and Cambridium Horny, 1957 (Mollusca Monoplacophora) in Invertebrate Phylogeny. – Intern. Geol. Congr., XXI Session, Norden, Part XXII; 92-101, 3 text-figs.

— & K. G. Wingstrand, 1959: The comparative anatomy of *Neopilina galatheae* Lemche, 1957 (Mollusca Monoplacophora). – Proc. XV. Intern. Congr. Zool. London: 378-380.

— — 1960: Classe des Monoplacophores. Monoplacophora (Odhner, 1940). – In: Traité de Zoologie. Anatomie, Systematique, Biologie, **5**, 2: 1787-1821, 23 text-figs.

Levring, T., 1960: A List of Marine Algae from Rennell Island. – The Natural History of Rennell Island, British Solomon Islands, **3**: 121-125.

Marshall, G. A. K., 1958: On Curculionidae (Coleoptera) from Rennell Island, Solomon Islands. – Ibid. **2**: 121-126, 2 pls.

Nielsen, Jørgen, 1961: Psettodoidea and Pleuronectoidea (Pisces, Heterosomata). – Atlantide Rep., **6**: 101-127, 8 text-figs., 1 pl.

Nørvang, Aksel: Schizamminidae, a New Family of Foraminifera – Ibid.: 169-201, 2 text-figs., 4 pls.

Powell, A. W. B., 1958: New Zealand Molluscan Systematics with Descriptions of New Species, Part 3. – Rec. Auck. Inst. Mus., **5**, 1-2: 87-91, 4 text-figs., 1 pl.

Scudder, G. G. E., 1958: Lygaeidae (Hemiptera) of Rennell and Bellona Islands. – The Natural History of Rennell Island, British Solomon Islands, **2**: 135-142, 1 text-fig.

Stubbings, H. G., 1961: Cirripedia Thoracica from Tropical West Africa. – Atlantide Rep., **6**: 7-41, 11 text-figs.

Tandan, B. K., 1958: Mallophaga (Insecta). Part II. – A New Species of *Ibidoecus* Cummings, 1916. – The Natural History of Rennell Island, British Solomon Islands, **2**: 151-154, 6 text-figs.

Tattersall, Olive S., 1961: Mysidacea from the Coasts of Tropical West Africa. – Atlantide Rep., **6**: 143-159, 3 text-figs.

Viette, P. E. L., 1954: Une nouvelle espèce de Lépidoptère brachyptère de l'île Campbell. – Ent. Medd., København, **27**, 1: 19-22, 1 text-fig.

Wolff, Torben, 1959: La faune hadale ou faune des profondeurs superieures à 6000-7000 mètres. – Terre et Vie, **106**, 2-3: 244-266, 4 text-figs., 1 pl.

— 1959: L'exploration des mers profondes. – La Nature, No. 3294, Oct. 1959: 425-431, 9 text-figs.

— 1960: The Hadal Community, an Introduction. – Deep-Sea Res., **6**, 2: 95-124.

— 1960: Die tödliche Laterne. Was noch keines Mennschen Auge sah: Lebewesen aus Tiefen bis 10.000 m. – Österreichischer Tierschutzkalender 1961, Wien: 55-58, 13 text-figs.

— 1961: The Deepest Recorded Fishes. – Nature, **190**: 283.

— 1961: A Bathyal-abyssal Hermit Crab with a Calcified Asymmetrical Abdomen. – Nature, **190**: 931-932.

GALATHEA REPORT

Scientific Results of the Danish Deep-Sea Expedition Round the World 1950–52

Volume 1, 1957-1959. 260 pp., 8 pls. Price: 90 Danish Kr.
Volume 2, 1956. 253 pp., 4 pls. Price: 75 Danish Kr.
Volume 3, 1959. 87 pp., 60 pls. Price: 60 Danish Kr.
Volume 4, 1961. 226 pp., 14 pls. Price: 95 Danish Kr.
Volume 5, 1961 (not complete)
Volume 6, 1962 (in print)

ATLANTIDE-REPORT

Scientific Results of the Danish Expedition to the Coasts of Tropical West Africa 1945–46

No. 1, 1950. 247 pp., 16 pls. Price: 35 Danish Kr.
No. 2, 1951. 303 pp., 2 pls. Price: 40 Danish Kr.
No. 3, 1955. 324 pp., 15 pls. Price: 50 Danish Kr.
No. 4, 1956. 212 pp., 5 pls. Price: 40 Danish Kr.
No. 5, 1959. 332 pp. Price: 60 Danish Kr.
No. 6, 1961. 262 pp., 9 pls. Price: 55 Danish Kr.
No. 7 (in print)

THE NATURAL HISTORY OF RENNELL ISLAND, BRITISH SOLOMON ISLANDS

Scientific Results of the Danish Rennell Expedition, 1951
and the British Museum (Nat. Hist.) Expedition, 1953

Volume 1: Vertebrates, 1958. 228 pp., 9 pls. Price: 45 Danish Kr.
Volume 2: Invertebrates, 1959. 234 pp., 35 pls. Price: 50 Danish Kr.
Volume 3: Botany and Geology, 1960. 132 pp., 10 pls. Price: 30 Danish Kr.
Volume 4: Invertebrates (not complete)

LIST OF DANISH VERTEBRATES

Anton Fr. Bruun and J. R. Pfaff: Fishes
J. R. Pfaff: Amphibians and Reptiles
Bernt Løppenthin: Birds
Magnus Degerbøl: Mammals

180 pp., one chart. Price: 10.50 Danish Kr.

Rate of exchange: 7 Danish Kroner equal to about 7 British sh. or one U. S. A. dollar

DANISH SCIENCE PRESS, LTD.

(Dansk Videnskabs Forlag, A/S)
Copenhagen

Reprinted from COPEIA, 1961, No. 3, pp. 288–292, September 22
Printed in U. S. A.

A New Genus and Species of Deepwater Ophidioid Fish from the Gulf of Mexico

Daniel M. Cohen

THIS paper is the first in a series of studies on the ophidioid fishes referred by some authors to the family Brotulidae. Preliminary observations by Dr. C. Richard Robins of the University of Miami and by myself indicate that our present state of knowledge gives us no way of separating the nominal families Ophidiidae (the family name with priority) and Brotulidae. Rather than assign the subjects of my studies to a family at the present time, I prefer to hedge and call them ophidioids, in the hope that further study will provide a firm basis upon which a classification may rest.

The opportunity to examine the remarkable collections of this group of fishes taken by the exploratory fishing investigations of the U. S. Fish and Wildlife Service in the Gulf of Mexico and in the Caribbean provided the original impetus for these studies. I am particularly indebted to Mr. Harvey Bullis for his kindness in sending me specimens, to Dr. Giles Mead of the Museum of Comparative Zoology, Harvard University, for allowing me to examine the holotype of *Acanthonus spinifer,* and to Dr. Vladimir Walters of the American Museum of Natural History for giving me access to the type of *Cherublemma lelepris.* Dr. C. Richard Robins kindly commented on the manuscript.

Although the deepwater ophidioids are probably the predominant fishes at abyssal depths, they are understandably rare in collections, many species being known from only one or a few specimens. My present studies are being carried on in the U. S. National Museum where I have available the important material reported upon by Goode and Bean and by Radcliffe and Smith. At this early stage in my own work, it is apparent that considerable confusion exists concerning the identity of many deepwater ophidioids, and it is hoped that by utilizing the available material, as well as additional specimens that may become available, it will be possible to gain greater insight into the phylogeny of this group.

Xyelacyba *gen. nov.*

Type species *Xyelacyba myersi sp. n.*

Diagnosis.—An ophidioid fish with the symphysis of the cleithra beneath the eyes; ventral fins located under the head immediately posterior to the symphysis of the cleithra; dorsal, caudal and anal fins continuous; pectoral fin with branched rays. Eyes present. Posterior nostril a large pit immediately in front of eye. Body and head covered with scales; a short, indistinct, lateral line present. Opercle and preopercle each with a strong, grooved spine projecting to or beyond the posterior margin of the head; several smaller spines on the preopercle; no spine on the snout. Pseudobranch present but reduced. Gill membranes joined to each other and free from the isthmus for a short distance in front of the symphysis of the cleithra. Some gillrakers elongated. Body compressed; head deep and broad; mouth terminal; dorsal profile of head rounded, snout blunt. Posterior-dorsal portion of maxillary free, not sheathed. Tongue large; vomerine and palatine dentition reduced to narrow bands.

Relationships.—Apparently nearest to *Acanthonus* Günther and *Tauredophidium* Alcock, although quite different from both. It shares with them similar armature on the opercle and preopercle, and possession of a deep and broad head and strongly compressed body. Some differences from the former are: absence of nasal spines (a double pointed spine present on the snout of *Acanthonus*); presence of a blunt snout and terminal mouth (snout more pointed and mouth inferior and included in *Acanthonus*); supramaxillary and posterio-dorsal portion of maxillary exposed (sheathed in *Acanthonus*); posterior nostril a prominent pit immediately in front of eye (closer to tip of snout than to eye in *Acanthonus*); skin translucent (transparent in *Acanthonus*). In addition, *Xyelacyba* has a shorter snout and a less attenuate body than *Acanthonus*. Other striking differences suggested by superficial observation of the limited material available are to be found in the musculature of the head and the osteology of the ethmoid region. Some differences from *Tauredophidium* are: presence of eyes, position of ventral fin origin close to or ahead of the level of the posterior margin of the maxillary, and distance between the bases of the ventral fins small, one-seventh or less, than the head length. In *Tauredophidium,* on the other hand, functional eyes are degenerate and buried beneath the scale-covered skin, ventral fins originate well behind the level of the posterior margin of the maxillary, and distance between ventral fins is about one-third the head length. In addition, the preopercular armature is less strongly developed in *Xyelacyba* than in *Tauredophidium*.

Comparisons have been made between the types of *Xyelacyba myersi* and the type of *Acanthonus spinifer,* several specimens of *Acanthonus* from the Gulf of Mexico, and illustrations and literature accounts of *A. armatus* (Günther, 1887; Alcock and MacGilchrist, 1905) and *Tauredophidium hextii* (Alcock, 1890, 1902; Alcock and Anderson, 1898). The generic name is taken from the Greek *xyele*—a kind of dagger—and *kybe*—head.

Discussion.—Radcliffe (1913) placed the genera *Sirembo* and *Hoplobrotula* in the subfamily Sirembinae of the Brotulidae. He defined the group as follows: "Clavicular bones greatly produced, meeting below the eye; ventral fins inserted under eyes behind tip of humeral symphysis." Trotter (1926) added the genus *Cherublemma*. *Xyelacyba* would seem to fall into this group as well, were it not for its resemblance, in certain respects, to *Acanthonus* and *Tauredophidium*. In the former there is some variation in the position of the symphysis of the cleithra ("humeral symphysis" of Radcliffe). Günther's (1878) figure of *A. armatus* shows this structure as being at about the same level as the eye. In Alcock and MacGilchrist's (1905) figure of *A. armatus* the symphysis is well behind the level of the eye. Koefoed (1927) states of a specimen identified as *A. armatus,* "Ventrals placed just below end of maxilla." This would mean the symphysis was behind the level of the eye, as is the case in several Gulf of Mexico specimens of *Acanthonus* which I have examined.

Tauredophidium apparently has the symphysis placed well behind the level of the posterior edge of the maxillary. It appears therefore that the single character used to distinguish the Sirembinae is one which is variable in the *Acanthonus-Xyelacyba-Tauredophidium* group, which differs from the Sirembinae in general body proportions, lateral line development, form and number of gillrakers, pseudobranch development, dentition, degree of development of head spines and probably numerous internal characters as well. Indeed the genera *Hoplobrotula* and *Sirembo* appear closer to the Ophidiidae (in the restricted sense) than to any other ophidioid fishes. As for *Cherublemma,* it is a juvenile form, and the type and only known specimen is in such poor condition that it is not possible to either confirm or deny much of Trotter's (1926) original description. The photograph (fig. 33) of the type, however, differs from *Sirembo*, the nearest relative of *Cherublemma* (according to Trotter) in showing a deeper body and head, and Trotter also notes the restricted lateral line. In both of these features, *Cherublemma* comes closer to *Xyelacyba* than to *Sirembo*.

In addition to the type of *Cherublemma lelepris* in the American Museum of Natural History, I have examined two specimens of *Hoplobrotula armata* and two specimens of *Sirembo imberbis* in the U. S. National Museum.

Xyelacyba myersi *sp. n.*

Figure 1

Holotype.—USNM 187058, "Oregon" Station no. 2577, lat. 27°48′ N., long. 88°45′ W., in the Gulf of Mexico, 850–1100 fathoms, July 30, 1959, 40 foot flat trawl. *Paratype.*—USNM 187059. Data as for the holotype. A third specimen, rather badly mutilated, USNM 187060, "Oregon" Station no. 2820,

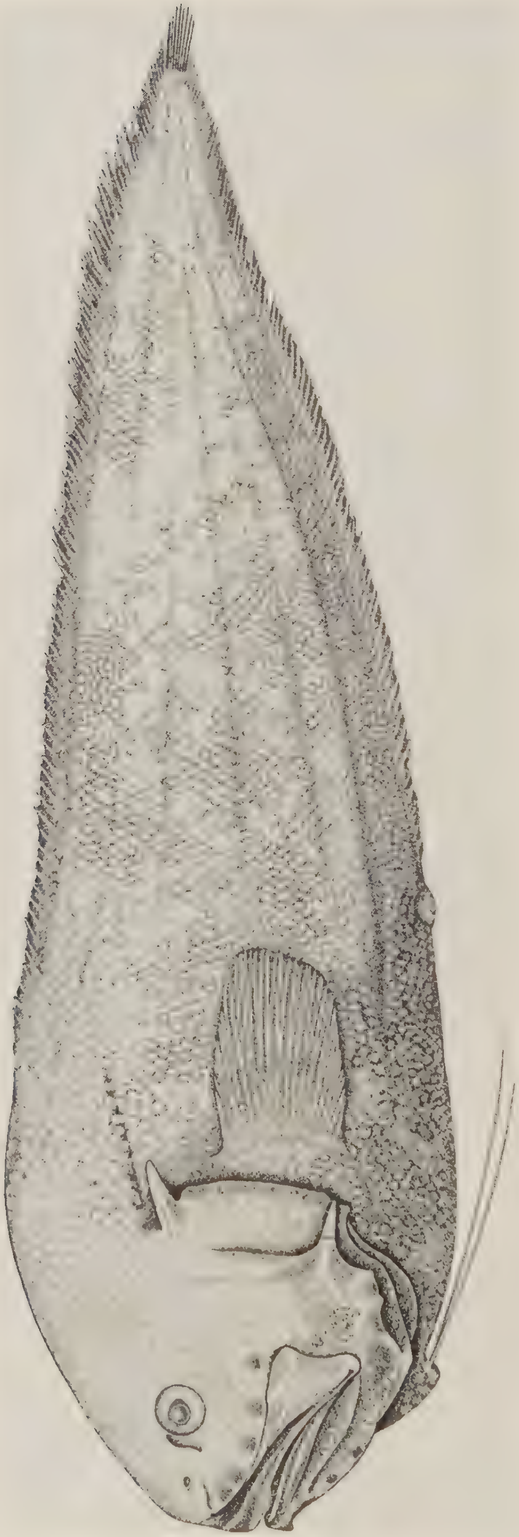


Fig. 1. Holotype of *Xyelacyba myersi*: Drawn by Mildred H. Carrington.

lat. 28°23′ N., long. 88°21.5′ W., in the Gulf of Mexico, 1000 fathoms, July 15, 1960, trawl.

Counts and measurements (in millimeters).—Data for holotype given first, followed by that for paratype in parentheses. D. 87 (?); A. 71 (?); pectoral 19 (19); ventral 2 (2); caudal 9 (9); gillrakers on first arch, upper arm with 4 (5) reduced, angle with 1 (1) long, lower arm with 15 (17) long plus 4 (4) reduced; lateral scale rows about 105 in holotype; branchiostegals 8 in paratype; vertebrae 49; standard length 464 (80); greatest depth 135 (21); depth at vent 126 (17.2); greatest width of head 98.5 (12.7); greatest width at level of vent 64 (4.9); preanal 208 (25.5); preventral 57.5 (8.6); length of pectoral fin 59 (9.5); length of ventral fin 115 (14.0); base of pectoral fin 36.8 (7.0); head length 104 (17.5); snout 28.6 (5.0); horizontal diameter of cornea 13.0 (3.0); tip of snout to posterior margin of maxillary 51 (10.0); greatest depth of maxillary 26.9 (4.5).

Description.—Body foreshortened, compressed; head deeper than long; head width greater than postorbital length of head. Deepest part of fish at level of pectoral fin base, tapering gently to the tail. Dorsal profile of head curving forward rather steeply to the blunt snout. Ventral profile of head rising steeply, interrupted by the pelvic girdle. Skin which covers the abdomen loose and flabby.

Both specimens have lost all of their scales; however, scale pockets are distributed over the entire body and head, although the pockets are not easily distinguishable at the caudal end of the fish. An indistinct lateral line originates at the angle of the opercle and runs posterio-dorsally for a short distance, but it does not reach the level of the vent.

Origin of dorsal fin over pectoral fin. Origin of anal fin close to vent, separated by about 17 mm. in the holotype and two mm. in the paratype. Dorsal, caudal and anal fins continuous; almost all of the dorsal and anal fin rays are broken off short; however, at least some of the dorsal rays near the posterior end of the fin appear to be branched. Pectoral fin inserted vertically, originating on a deep, scale-covered peduncle. Pectoral rays branched, not elongated, the fin extending almost to the level of the origin of the vent in the holotype, slightly beyond in the paratype. Axil of the pectoral fin lacking scales, covered with a thin membranous tissue similar to the lining of the gill cavity, dark brown in the holotype, gray-brown in the paratype. Cleithrum extending forward ventrally to a point beneath the eye. Ventral fins originating behind the symphysis of the cleithra, in the holotype in line with posterior end of the maxillary, in the paratype in line with the posterior margin of the eye; each fin with two simple rays, the medial ray longer, reaching almost to the vent. Bases of the ventral fins separated by a distance of 10 mm. in the holotype, 1.5 mm. in the paratype.

A reduced pseudobranch is present, bearing two or three filaments in the holotype and four filaments in the paratype.

Opercle a narrow bone carrying a long, posterio-dorsally directed spine at the upper angle. The spine has a prominent lateral ridge with a deep groove on either side. The base of the opercular spine is a flat, platelike structure dorsally and a long, narrow process ventrally, running almost to the base of the longest preopercular spine. In the paratype the entire anterior edge of the base of the opercular spine forms a movable joint with the edge of the preopercle, thus allowing the spine to move in an arc of about 45 degrees. The preopercle, also a narrow bone, carries a series of spines at its lower angle. The anterior margin of the preopercle in the paratype articulates in a movable joint with its anterior neighbor, presumably the hyomandibular. The preopercle swings forward in an arc of about 90 degrees. When both of the opercular elements are extended as far as possible, they lock in place, giving the fish an extremely fierce countenance when viewed head-on. Alcock (1890) notes that the opercle and preopercle of *Tauredophidium* are similarly movable though he does not mention a locking mechanism. On the preopercle the dorsal-most, posterio-ventrally directed spine is the longest, being about equal to the opercular spine, which it also resembles in its arrangement of grooves and ridges. The other two preopercular spines are much less prominent. The long opercular and preopercular spines are proportionally longer in the paratype. A blunt spinous projection is also present below the posterior end of the maxillary. I can not tell for certain from what bone it projects, but it may be the angular. Spines are not present on the snout.

The eyes are sunken and have a smaller diameter than the circle of clear skin through which they are visible. The iris is very narrow; the lens completely fills the pupil.

The posterior nostril is a prominent pit, with its vertical dimension about two times the horizontal. It is separated from its anterior partner by a distance equal to the height of the posterior nostril. The anterior nostril is a round opening with raised edges. Anterior and ventral to the anterior nostril a fold of skin covers the entrance to a subcutaneous cavity on the snout.

In the holotype, a series of five, darkly-pigmented pores are arranged in a line above the upper jaw. A pair of similar pores are found at the mid-length of each mandible. A series of small papillae, visible only in the holotype, are found in the area of the nostrils.

The dorsal portion of the maxillary is sheathed anteriorly; however, the posterior part of the bone is completely exposed. The posterior margin of the maxillary is very slightly concave. A prominent ridge is present along the ventral margin of the supra-maxillary, where it joins the maxillary. At the anterior tips of both the upper and lower jaws the tooth-bearing areas are separated by narrow, edentulous gaps. The vomerine and palatine dentition is reduced, with the head of the vomer carrying only three diagonal rows of teeth and the wings of the vomer only a single row, as do the palatines. The tongue is an enlarged structure, almost as wide as the mouth. The tongue lacks teeth; however, the basihyals behind it bear three tooth-bearing areas.

The scale pockets of the holotype are uniform, dark brown. The vertical fins and the belly are very dark; the ventral surface of the head is dark brown; the opercular area and the lips are bluish brown. The remainder of the head is white.

Named for Professor George Sprague Myers, my teacher in ichthyology.

Literature Cited

Alcock, A. 1890. Natural history notes from H. M. Indian Marine Survey Steamer "Investigator," Commander R. F. Hoskyn, R. N. commanding.—No. 16. On the bathybial fishes collected in the Bay of Bengal during the season 1889–90. *Ann. Mag. Nat. Hist. Ser. 6, 6:197–222, pls. VIII–IX.*

———. 1902. A naturalist in Indian seas. *John Murray, London. 328 p.*

———, and A. R. S. Anderson. 1898. Illustrations of the zoology of the Royal Indian Marine Survey Ship "Investigator," under the command of Commander T. H. Heming, R. N. Fishes.—*Part V, pls. XVIII–XXIV. Office of the Superintendent of Government Printing, Calcutta.*

———, and A. C. MacGilchrist. 1905. Illustrations of the zoology of the Royal Indian Marine Survey Ship "Investigator," under the command of Captain T. H. Heming, R. N. (Retired). Fishes.—*Part VIII, pls. XXXVI–XXXVIII. Office of the Superintendent of Government Printing, Calcutta.*

Günther, A. 1887. Report on the deep-sea fishes collected by H. M. S. *Challenger* during the years 1873–1876. *Rept. Sci. Res. Challenger, 1873–76, Zool., vol. XXII, lxv + 333. LXXIII pls.*

Koefoed, E. 1927. Fishes from the sea-bottom. *Rept. Sci. Res. "Michael Sars" N. Atlant. Deep-Sea Exped., 1910, vol. 4, pt. 1, 148 p., 6 pls.*

Radcliffe, L. 1913. Descriptions of seven new genera and thirty-one new species of fishes of the families Brotulidae and Carapidae from the Philippine Islands and the Dutch East Indies. *Proc. U. S. Natl. Museum 44:135–76, pls. 7–17.*

Trotter, Elizabeth S. 1926. Brotulid fishes. *Zoologica (N. Y.) 8107–25.*

Ichthyological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, U. S. National Museum, Washington, D. C.

22

The Distribution of Eyed Flounder and Lanternfish Larvae in the Georges Bank Area

JOHN B. COLTON, JR.

Reprinted from COPEIA, 1961, No. 3, pp. 274-279, September 22
Printed in U.S.A.

Reprinted from COPEIA, 1961, No. 3, pp. 274-279, September 22
Printed in U. S. A.

The Distribution of Eyed Flounder and Lanternfish Larvae in the Georges Bank Area

JOHN B. COLTON, JR.

CONSIDERING its proximity to the Gulf Stream, one of the most unusual oceanographic features of the Georges Bank area is that it is so little subject to tropical influences, either in the physical character of its water or in its fauna or flora. Normally, the distribution of density imposes an impassible barrier to surface drift from the southward and it is only under exceptional conditions, i.e., strong and prolonged southerly winds, that any overflow of tropical or "Gulf Stream" water occurs. (For a detailed discussion of the origin and interrelationships of coastal, slope, and Gulf Stream water and the influence of oceanic water on the physical and biological properties of water over the continental shelf, see Bigelow, 1927, Iselin, 1936 and 1939, and McLellan, 1957.) Such a drift of tropical water over Georges Bank was evidenced during September, October, and November 1956 when 129 postlarval specimens of *Bothus ocellatus* (Agassiz) and 561 myctophid postlarvae were collected in 1-meter net and Hardy Plankton Recorder tows in the upper 10 meters of water. These samples were collected on the FWS Charter Vessel M/V *Silver Bay* during cooperative cruises of the United States Fish and Wildlife Service and the Fisheries Research Board of Canada designed to study the early life history of herring in the offshore waters of the Bay of Fundy and the Gulf of Maine (Tibbo, Legaré, Scattergood, and Temple, 1958). The collections represent a more northwesterly record for *Bothus ocellatus* than has been reported previously and demonstrate a marked correlation between the distribution of these tropical fish larvae and the distribution of temperature.

DESCRIPTION OF LARVAE

The specimens of *Bothus ocellatus* ranged in total length from 4.5 to 42 mm. The identification is based on descriptions of morphological characteristics of this species given by Kyle (1913) and Norman (1934). The asymmetry of the ventral fins, one being short based and supported by the pelvic bone (blind side) and the other (ocular side) being elongate, extending forward to the urophyal,

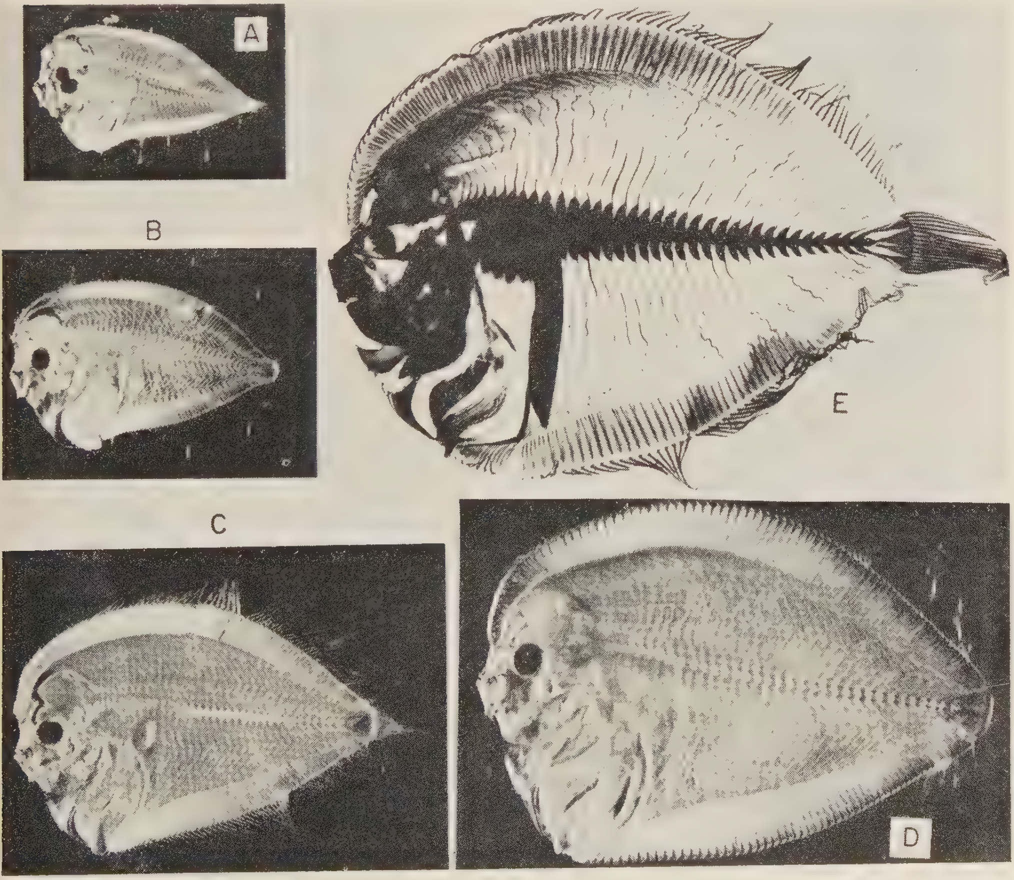


Fig. 1. Postlarval *Bothus ocellatus*, A—6.5 mm., B—8.0 mm., C—11.0 mm., D—15.0 mm., E—19.0 mm.

supported by a cartilaginous plate placed in advance of the cleithra, and with its anterior ray well in advance of the first ray of that on the blind side, places these larvae in the sub-family Bothinae (see Fig. 1 E). *Bothus* is the only genus of the sub-family found on the eastern side of the Atlantic ocean. Dorsal fin ray counts (82–88) and anal fin ray counts (63–65) restrict the species possibilities to *ocellatus, podas* (DeLaroche), and *mellissi* (Norman). Of these three species, only *ocellatus* is found along the Atlantic coast of America.

Kyle (1913) tentatively separated larval and postlarval *Bothus* found west of 35° W. Long. into two species: *B. atlanticus,* having an average of 26 caudal vertebrae and belonging to the Sargasso Sea and mid-Atlantic water further south and only approaching land at the West Indies, and *B. ocellatus,* having an average of 27 caudal vertebrae and occurring along the South American mainland and along the outer edge of the Gulf Stream to the vicinity of the Newfoundland Banks. The total number of vertebrae (atlas through penultimate) in our specimens was 36 (abdominal 10, caudal 26). This number corresponds to that of Kyle's *"atlanticus"* species. Norman (1934), however, concluded that it is improbable that *"atlanticus"* is a species endemic to the Sargasso Sea area and that the majority of *Bothus* larvae captured in the mid-Atlantic are of American origin. He grouped Kyle's two species (*"atlanticus"* and *"ocellatus"*) into the one species *Bothus ocellatus.*

Photographs of four cleared and one stained specimen of *Bothus ocellatus* col-

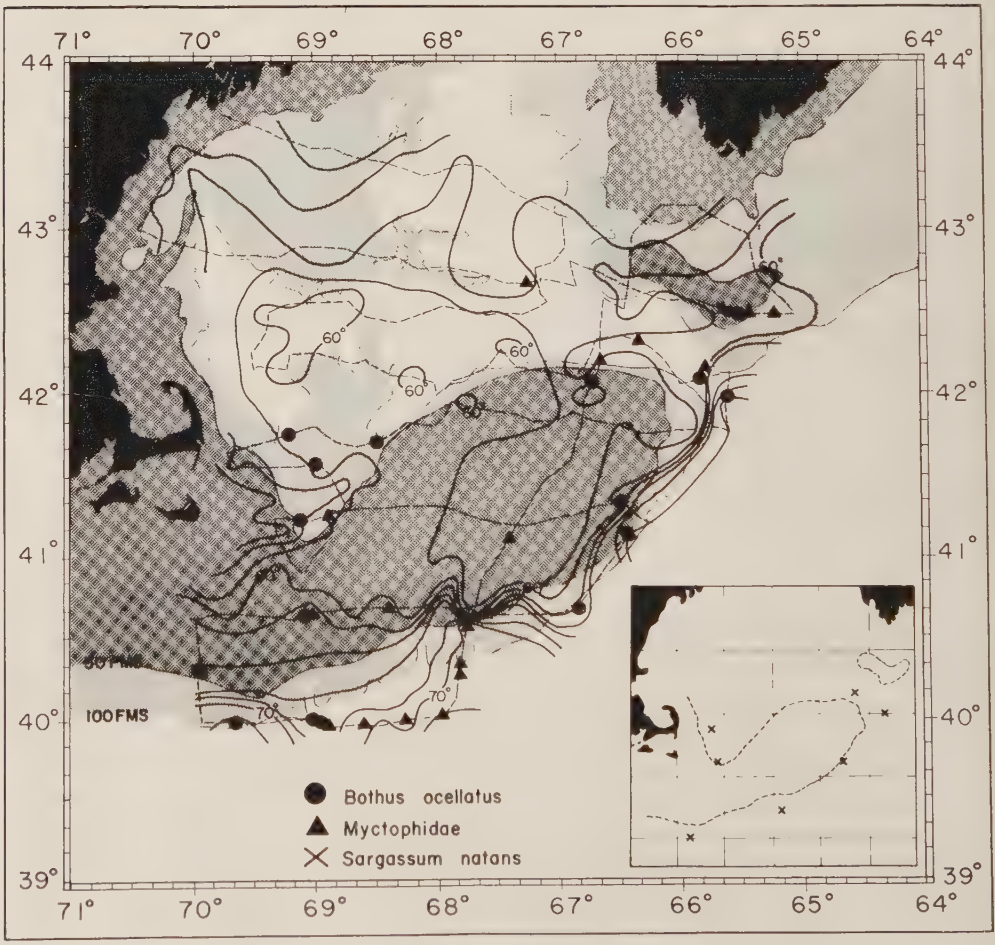


Fig. 2. Distribution of *Bothus ocellatus* and myctophid postlarvae, *Sargassum natans,* and surface temperature, M/V *Silver Bay* Cruise No. 1, September 21–October 5, 1956.

lected in the Georges Bank area are shown in Fig. 1. The eyes of all specimens were still symmetrical, attesting to the long pelagic life of this species. (In *P. bodas*, for example, metamorphosis does not take place until the larvae have reached a length of 30 to 40 mm. (Kyle, 1913).) The general characteristics of the larvae correspond closely to those of specimens of *B. podas* pictured by Kyle (1913:97–8, figs. 13–15). The absence of pigment in any of the larvae was possibly due, as suggested by Kyle, to the reaction to formalin. The dorsal tentacle, which was cleft in our preserved specimens, had disappeared in larvae 8–10 mm. in length which corresponds to the length at which the dorsal tentacle disappears in *B. podas*.

The myctophid postlarvae ranged in total length from 4.5 to 20.0 mm. The incomplete literature on the larval stages of the Myctophidae makes positive identification of these larvae impossible at this time. The most distinctive external characteristics of these larvae are their large eyes, wide mouth, the location of the vent about midway of the body, a deeply forked tail, a black pigment patch over the vent, a dorsal and ventral bar of pigment spots just anterior to the caudal fin, and four pigmented photophores, one at the base of each pectoral and ventral fin.

Distribution

The distribution of *Bothus* and myctophid postlarvae and of surface temperature during September, October, and November is shown in Fig. 2, 3, and 4. The area of occurrence of *Bothus* and myctophid postlarvae during each month was similar, with neither

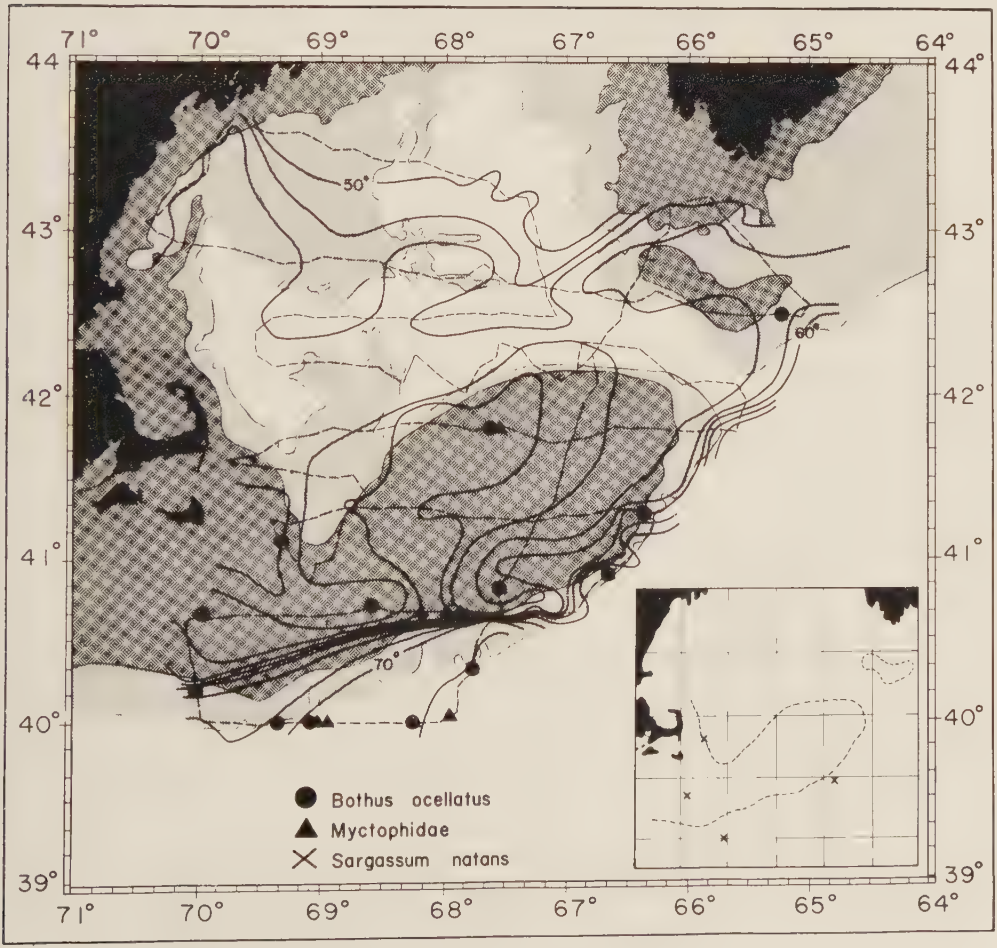


Fig. 3. Distribution of *Bothus ocellatus* and myctophid postlarvae, *Sargassum natans*, and surface temperature, M/V *Silver Bay* Cruise No. 2, October 15–25, 1956.

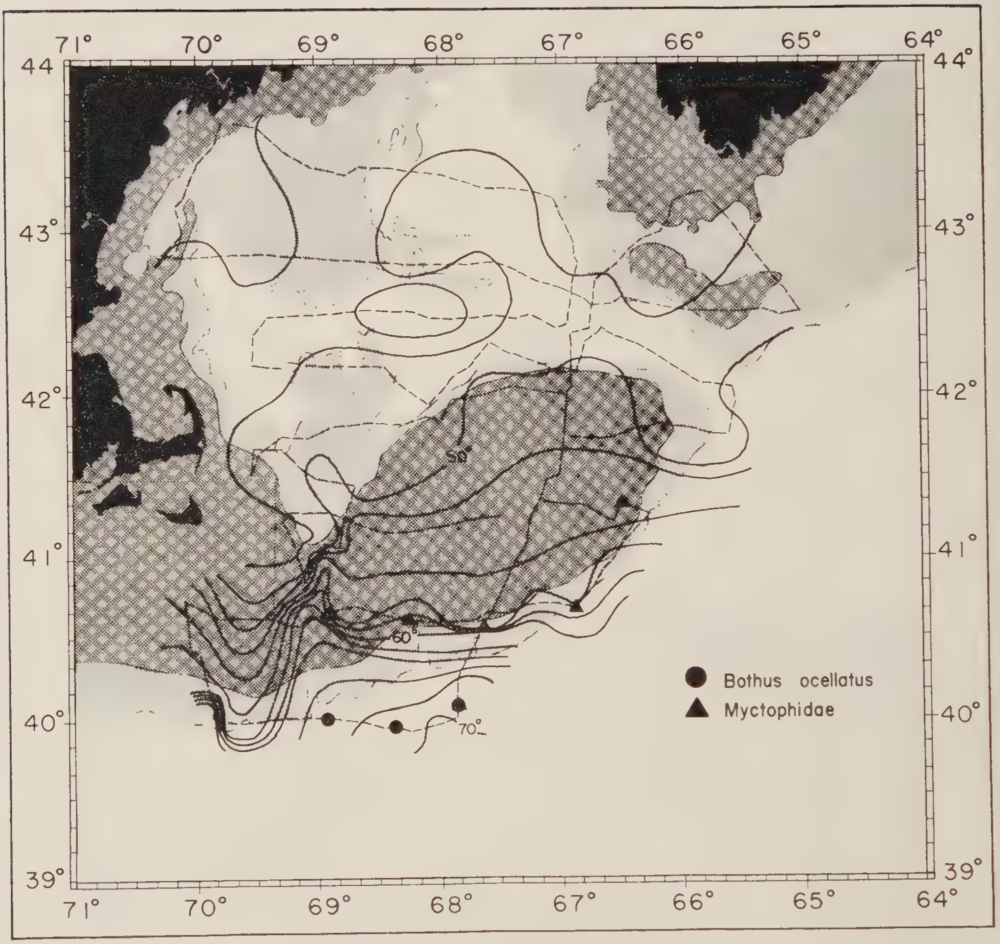


Fig. 4. Distribution of *Bothus ocellatus* and myctophid postlarvae, and surface temperature, M/V *Silver Bay* Cruise No. 4, November 14–30, 1956.

species being present in water much colder than 58°F. During September the surface water over Georges Bank and Browns Bank and over the southern part of the Gulf of Maine was warmer than 58°. In October surface water warmer than 58° occurred only over the eastern and southern edge of Georges Bank, Georges Shoals, and the southern part of the Great South Channel. In November surface water warmer than 58° was present only along the southern edge of Georges Bank. The southerly shift and decrease in areal extent of the warm surface water coincided with a similar change in the distribution of both *Bothus* and myctophid postlarvae. By December surface temperatures over the whole area had fallen below 58° and no *Bothus* or myctophid postlarvae were found. It would appear that these two species are unable to survive in water much colder than 58°F.

Discussion

Wind conditions during late August and early September, as deduced from daily observations at the Georges Shoal Texas Tower, were not unusual for this time of year. Also, the surface temperatures over Georges Bank during the fall of 1956 were not exceptionally high and are not an indication in themselves of an intrusion of tropical water. However the presence of fragments of Gulf weed (*Sargassum natans*) in the meter-net material during September and October is sure evidence of an actual influx of Gulf Stream water. The locations at which *Sargassum* was collected are shown in Fig. 2 and 3. The distribution of *Sargassum* was similar to that of the *Bothus* and myctophid larvae.

The similarity of the distribution of *S. natans* and of *Bothus* and myctophid postlarvae suggests a common origin. The fact that *S. natans* is native to the Caribbean, an area to which *B. ocellatus* is a common species, indicates that the *Bothus* postlarvae were transported from the latter area by the Gulf Stream system. Such a prolonged journey appears possible, for *Bothus* larvae with the eyes still symmetrical have frequently been collected in the mid-Atlantic (Norman, 1934). The Myctophidae are bathypelagic fish, and collections of them in the north Atlantic have been made principally in the Gulf Stream and in the slope water along the edge of the continental shelf. Only mature specimens of two species of myctophids have been recorded within the Gulf of Maine, the headlight fish, *Diaphus effulgens* (Goode and Bean) and the lanternfish, *Myctophum affine* (Lütken) (Bigelow and Shroeder, 1953). Apparently the myctophid postlarvae were also carried northward by the Gulf Stream system.

That similar instances of an overflow of tropical water onto Georges Bank have not been observed more often may be due in part to the infrequency of coverage of this area during the late summer and early fall when winds are predominantly southwesterly and temperatures over Georges Bank are at a maximum, both conditions being conducive to a breakdown of the normal density barriers existing between coastal and oceanic water. Because existing hydrographic conditions may not indicate that such an overflow has occurred, indicator species are of great value in detecting such phenomena. Subsequent observations during the fall of the year may demonstrate a more frequent intrusion of tropical water over Georges Bank than has been suspected heretofore.

Acknowledgments.—I wish to express my appreciation to Mr. Jack W. Gehringer, Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia and to Dr. Robert H. Gibbs, Jr., Department of Biology, Boston University for examining specimens of myctophid larvae and to Mr. Lynn C. Wall of the Eastman Kodak Company for the photographs of the larval specimens.

LITERATURE CITED

BIGELOW, HENRY B. 1927. Physical oceanography of the Gulf of Maine. *Bull. U. S. Bur. Fish. 40(2):511–1027.*

BIGELOW, HENRY B., AND WILLIAM C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *U. S. Fish and Wildl. Serv. Fish. Bull. 74:1–577.*

ISELIN, C. O'D. 1936. A study of the circulation of the western North Atlantic. *Pap. in Phys. Oceanogr. and Meteor. 4(4):1–101.*

———. 1939. Some physical factors which may influence productivity of new England's coastal waters. *J. Mar. Res. 2(1):74–85.*

KYLE, H. M. 1913. Flat-fishes (Heterosomata). *Rep. Danish Ocean. Exped. 1908–10, II, A. 1, 150 pp. 4 pls.*

MCLELLAN, H. J. 1957. On the distinctness and origin of the slope water off the Scotian Shelf and its easterly flow south of the Grand Banks. *J. Fish. Res. Bd. Canada, 14(2):213–39.*

NORMAN, J. R. 1934. A systematic monograph of the flatfishes (Heterosomata), Vol. I— Psettodidae, Bothidae, Pleuronectidae. *British Museum, London, viii + 459 pp.*

TIBBO, S. N., J. E. HENRI LEGARÉ, LESLIE W. SCATTERGOOD, AND R. F. TEMPLE. 1958. On the occurrence and distribution of larval herring (*Clupea harengus*) in the Bay of Fundy and the Gulf of Maine. *J. Fish Res. Bd. Canada, 15(6):1451–69.*

U. S. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, BOOTHBAY HARBOR, MAINE.

23

J. B. COLTON, Jr., K. A. HONEY,
and R. F. TEMPLE

THE EFFECTIVENESS OF SAMPLING METHODS USED TO STUDY THE DISTRIBUTION OF LARVAL HERRING IN THE GULF OF MAINE

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
POUR L'EXPLORATION DE LA MER
VOL. XXVI. No. 2. 1961

The Effectiveness of Sampling Methods Used to Study the Distribution of Larval Herring in the Gulf of Maine

By

John B. Colton, Jr., Kenneth A. Honey, and **Robert F. Temple**

U. S. Fish and Wildlife Service, Boothbay Harbor, Maine

Introduction

In 1956, 1957, and 1958, the Fisheries Research Board of Canada and the United States Fish and Wildlife Service conducted cooperative cruises to study the early life history of herring in the offshore areas of the Bay of Fundy and the Gulf of Maine, (Tibbo, *et al.*, 1958). The purpose of that investigation was to determine spawning and nursery areas, to obtain information on survival, growth, and dispersal of larvae, and to study the relationship of spawning and larval drift to the abundance of "sardine" herring in the inshore areas of Maine and New Brunswick.

The work of Tibbo, *et al.* (1958), was based on macroscopic examination of metre-net and Hardy Plankton Recorder material. In the present paper a more detailed analysis of the data is made to determine the efficacy of the sampling techniques in programmes of this nature.

Materials and Methods

For this analysis only material from United States Fish and Wildlife Service cruises of September, October, November 1956, and January, February 1957, has been included as the coverage during these cruises was more complete than that of any other series. The sampling gear used was the Hardy Plankton Recorder (Hardy, 1936) and 1 m ring-nets. Hardy Plankton Recorders were towed continuously at the surface and at 10 m at a speed of approximately 10 knots. The recorders were equipped with a 3/4 inch square mouth opening and 60 mesh-per-inch filtering silk. The propellor setting was such that each 2 inch section of filtering silk represented approximately 5 miles of tow (3·4 cubic metres of water filtered). Fifteen-minute oblique metre-net tows (10 m to

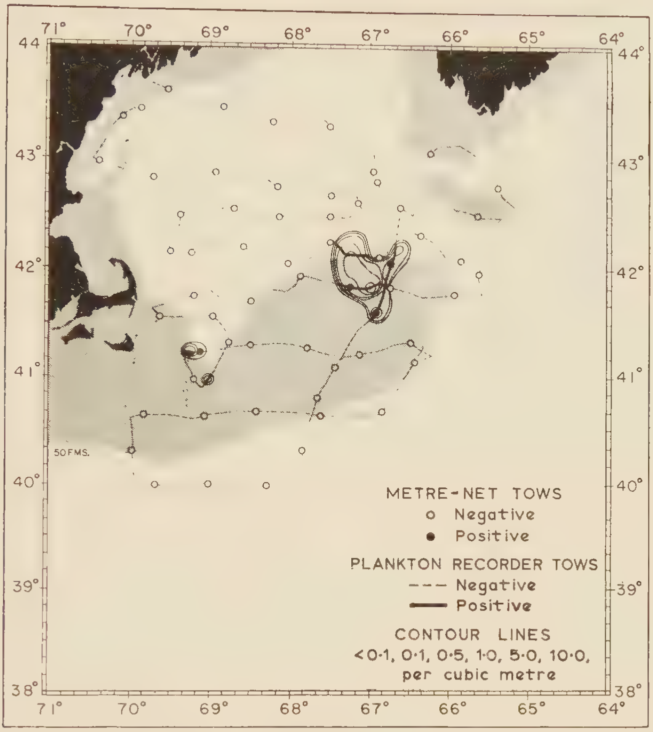

71°
70°
69°
68°
67°
66°
65°
64°
44°
43°
42°
41°
40°
39°
38°
50 FMS.
METRE-NET TOWS
○ Negative
● Positive
PLANKTON RECORDER TOWS
--- Negative
— Positive
CONTOUR LINES
<0·1, 0·1, 0·5, 1·0, 5·0, 10·0, per cubic metre

Figure 1. The abundance and distribution of larval herring, "Silver Bay" Cruise No. 1, 21. September–5. October 1956.

surface) were made every 4 hours. The nets were constructed of No. 0 silk or nylon and the towing speed was about 3 knots. Larval fish of all species were removed, counted, and measured. All lengths recorded in this paper are total lengths and all numbers are in terms of numbers per cubic metre of water filtered.

Distribution, Abundance, and Length of Larval Herring

Charts showing cruise lines and the distribution and abundance of larval herring as determined by metre-net and Hardy Plankton Recorder samples for September, October, and November 1956, and January and February 1957, are presented in Figures 1, 2, 3, 4, and 5. The abundance figures for the Hardy Plankton Recorder material are an average of the catch at the surface and at 10 m.

The distribution of larval herring as determined by Hardy Plankton Recorder material is in general of a more detailed nature than that indicated by metre-net tows. This is due largely to the continuity of the Hardy Plankton Recorder sample. In several instances larvae were caught by the recorders and not by the metre net, but usually the differences in distribution as indicated by the two sampling methods are due to the fact that the Hardy Plankton Recorder caught larval herring in areas not sampled by the metre nets. There are, however,

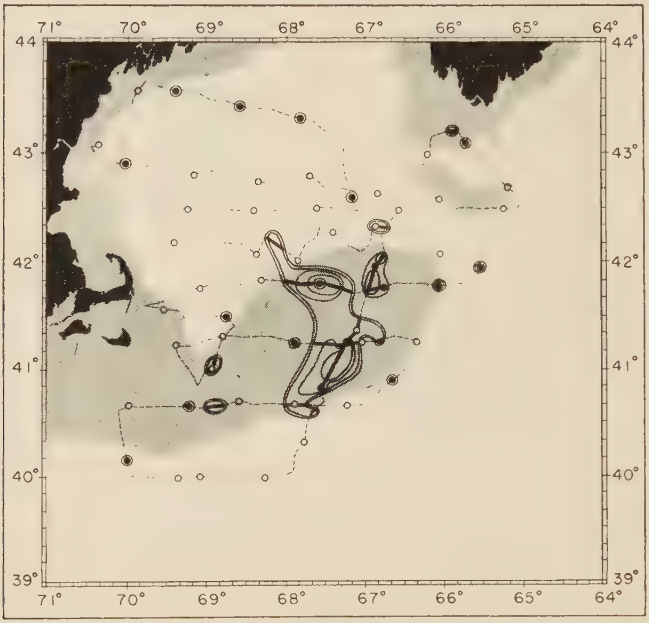

71°
70°
69°
68°
67°
66°
65°
64°
44
44°
43°
43°
42°
42°
41°
41°
40°
40°
39°
39°

Figure 2. The abundance and distribution of larval herring, "Silver Bay" Cruise No. 2, 15.–25. October 1956.

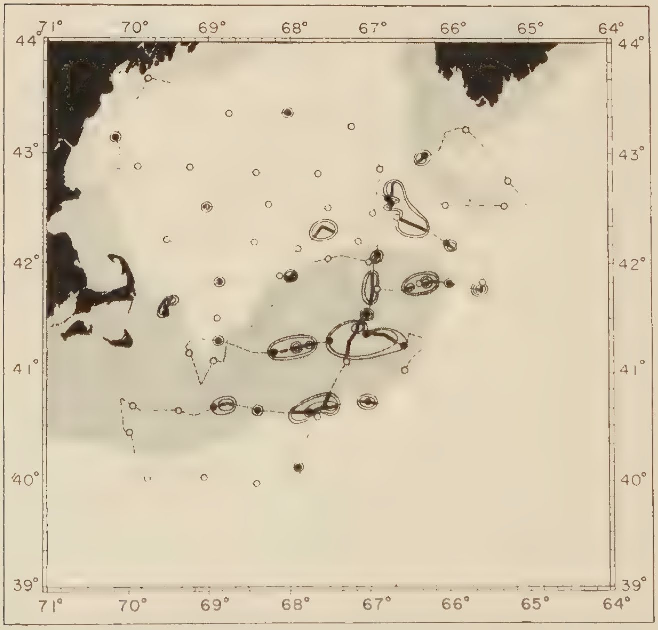

71°
70°
69°
68°
67°
66°
65°
64°
44
44°
43°
43°
42°
42°
41°
41°
40°
40°
39°
39°

Figure 3. The abundance and distribution of larval herring, "Silver Bay" Cruise No. 4, 14.–30. November 1956.

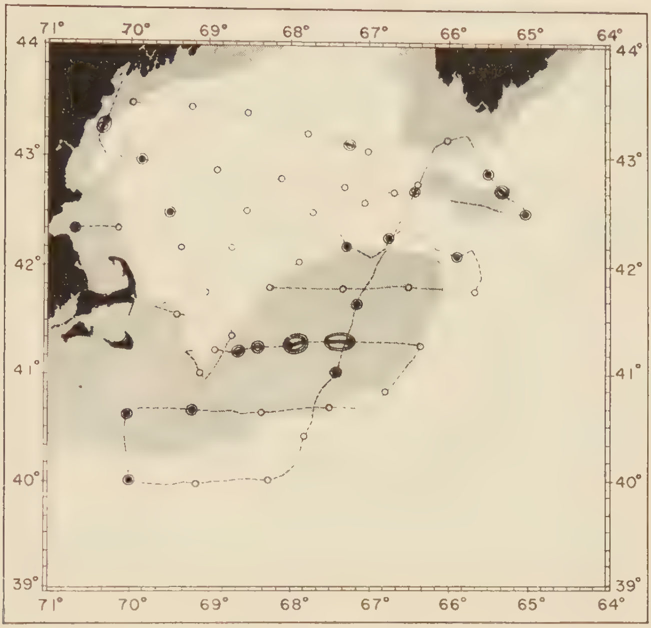

71°
70°
69°
68°
67°
66°
65°
64°
44
43°
42°
41°
40°
39°

Figure 4. The abundance and distribution of larval herring, "Delaware" Cruise No. 57–1, 28. January–4. February 1957.

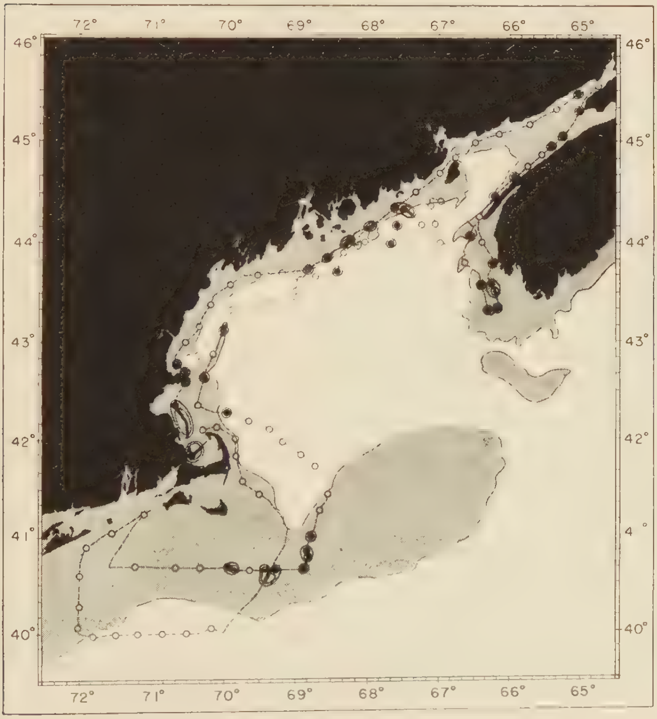

72°
71°
70°
69°
68°
67°
66°
65°
46°
45°
44°
43°
42°
41°
40°

Figure 5. The abundance and distribution of larval herring, "Albatross" Cruise No. 88, 19.–28. February 1957.

Table 1

Comparison of the average number of larval herring per m^3 as indicated by Hardy Plankton Recorder and metre-net samples

	Plankton Recorder	Metre net
"Silver Bay" Cruise No. 1	·100	·080
"Silver Bay" Cruise No. 2	·060	·090
"Silver Bay" Cruise No. 3	·040	·020
"Delaware" Cruise No. 57–1	·008	·003
"Albatross" Cruise No. 88	·011	·002
Average	·044	·039

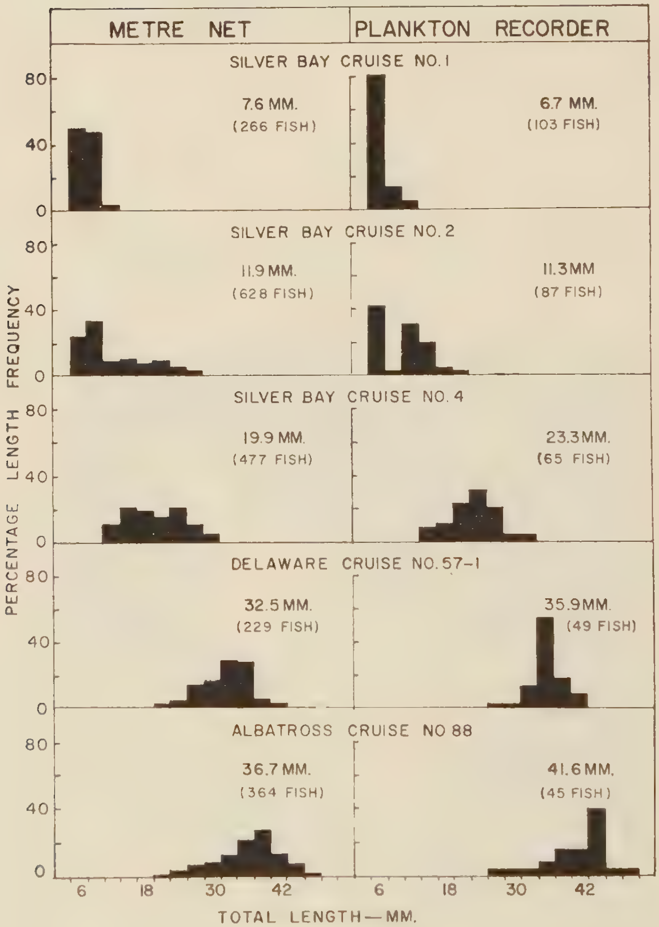


Figure 6. Length frequency and average length of herring larvae, September, October, November 1956, and January, February, 1957. Data are combined in 3 mm size groups.

many cases where concentrations of larval herring are indicated in the metre-net samples and not in the Hardy Plankton Recorder material. In all but two of these tows ("Silver Bay" Cruise No. 2) the concentration of larval herring was less than 0·1 per m^3. The small volume of water filtered by the Hardy Plankton Recorder in a 5-mile tow is not sufficient to indicate the presence of larvae in such slight concentrations.

In all cruises except "Silver Bay" No. 2 the average abundance of larval herring as indicated by the Hardy Plankton Recorder material was greater than that indicated by the metre-net collections (Table 1). The ratio of the number of larvae per cubic metre caught in the Hardy Plankton Recorder to that caught in the metre net increased with time and with length of larvae.

In Figure 6 the length frequency and average length of herring larvae caught in the Hardy Plankton Recorder and metre net are shown. With the exception of "Silver Bay" Cruises Nos. 1 and 2, the average length of recorder-caught larvae was significantly greater than the average length of larvae caught in metre-net tows. These differences in average length are most likely due to greater escapement of the larger larvae from the relatively slow-moving metre nets. Such a variation in the average length of larvae results in a marked difference in the approximate measure of growth obtained by plotting average lengths of larvae caught by the recorder and metre net during each month.

Diurnal Variation in Abundance and Length

Tibbo, *et al.* (1958), noted that greater numbers of larval herring were taken in 1 m nets during the night than during the day, that the proportion of larvae caught during the night increased with an increase in length of the larvae, and that the ability of the larger larvae to avoid capture accounted for such variations. Bridger (1956) demonstrated an increase in the night/day ratio of larval herring taken in vertical Helgoland net hauls with an increase in larval size and the ability of the larvae to escape slow-moving nets. The high speed of tow reduces the effect of escapement in Hardy Plankton Recorder sampling.

Surveys of the Georges Bank area during 1953, 1955, and 1956 showed that although the night catches of larval haddock, cod, hake, and flounder species in metre-net tows were markedly greater than the day catches, there was no appreciable variation in the average number or length of larvae caught in the Hardy Plankton Recorders during the day and night (Colton, unpublished data). During the survey under discussion, however, the night/day ratio of larval herring taken in the metre net and the Hardy Plankton Recorder is similar (Table 2).

With the exception of the prolarvae1) caught in the metre-net tows of "Silver Bay" Cruises 1 and 2 and the Hardy Plankton Recorder tows of "Silver Bay" Cruise 1, the greater percentage of herring larvae was taken during the night. The average length of the larvae in both the metre net and recorder was also generally greater during the night than during the day. This increase in abun-

---

1) The following allocation proposed by Hubbs (1943) was used in the separation of the early stages of fish:—

Prolarva = Larva still bearing yolk.
Postlarva = From absorption of yolk to time when adult characteristics assumed.

Table 2

Percentage abundance and average length of larval herring during the day (sunrise to sunset) and night (sunset to sunrise)

	Metre Net				Plankton Recorder			
	Day		Night		Day		Night	
	%	Average length (mm)	%	Average length (mm)	%	Average length (mm)	%	Average length (mm)
"Silver Bay" Cruise No. 1	79	6·1	21	9·0	94	6·1	6	6·9
"Silver Bay" Cruise No. 2	93	6·8	7	13·3	35	7·2	65	14·1
"Silver Bay" Cruise No. 4	2	19·4	98	18·4	28	20·9	72	22·6
"Delaware" Cruise No. 57–1	1		99	32·2	6	32·0	94	36·1
"Albatross" Cruise No. 88	1	30·0	99	39·6	0		100	42·1
Average	35		65		33		67	

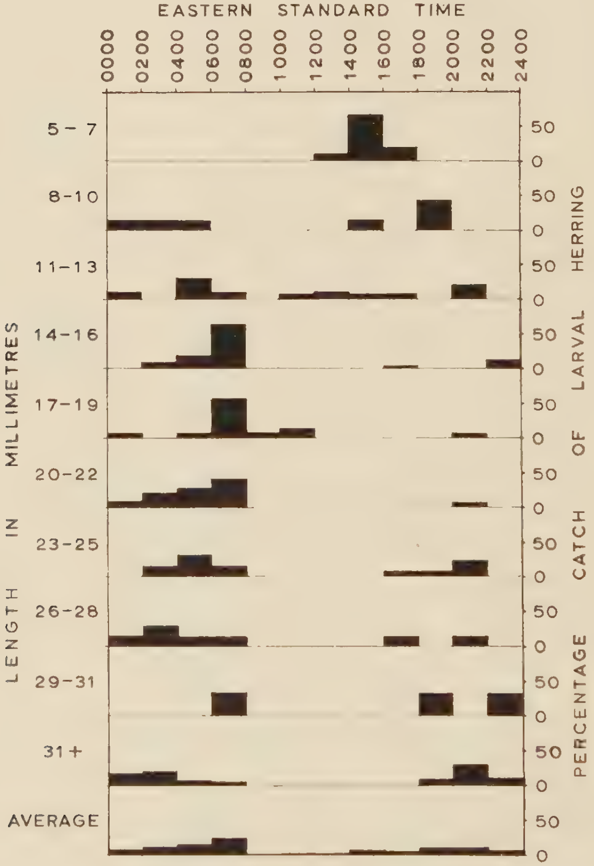


Figure 7. Percentage Recorder catch of larval herring by time, September, October, November 1956, and January, February 1957. Time is Eastern Standard Time.

dance and size during the night in the metre-net material is undoubtedly due in part to escapement of the larger larvae during the day, but the fact that there is also an increase in the average size and abundance during the night in the recorder catches indicates that larval herring move up to the surface layers during the night and that the magnitude of these diurnal movements increases with the size of the larvae.

That diurnal migration of herring does occur is evidenced by a comparison with the day and night catch of red hake (*Urophycis chuss*) during these cruises. In abundance and size range (3·5–45·0 mm) this species was similar to the herring. In the metre-net catches, the day and night distribution was similar to that of the herring (day, 32%; night, 68%), but in the recorder equal numbers were caught during the day and night (day, 49%; night, 51%). The average size of the red hake caught in the metre net was greater during the night than during the day, but of equal size during the day and night in the recorder. Thus escapement does not appear to be the only cause for the variation in the abundance of larval herring during the day and night.

In Figure 7 the percentage of the total recorder catch of larval herring in 3 mm length groups for 2-hour time intervals is shown. The average time of sunrise was 0634 and the average time of sunset was 1717 (Eastern Standard Time). With the exception of the 5–7 mm larvae caught during September more larval herring of all size groups were caught during the night. No larval herring larger than 19 mm were caught during the daylight hours. The maximum catches tended to occur just before sunrise. The predominance of the 5–7 mm larvae in the daylight hours appears to be due to inadequate sampling, as these recently hatched larvae were concentrated in a small area on the northern edge of Georges Bank (Fig. 1), which was only sampled during the daytime. The fact that they were captured during the day in both the metre net and the recorder, however, indicates that prolarvae and early postlarvae are physically incapable of undertaking appreciable horizontal or vertical movements and that adequate sampling would show equal abundance during the day and night.

The data on day and night distribution coupled with the fact that more larvae were caught in the recorder towed at the 10 m level in both day (87%) and night (76%) indicate that postlarval herring only occur in appreciable numbers in the surface layers during the night, that the extent of this diurnal migration increases with the size of the larvae, and that the depth of maximum abundance is below the 10 m level.

Discussion

This analysis reveals two aspects of the behaviour of larval herring, namely escapement and diurnal migration, that must be considered before any attempt is made to estimate quantitatively their abundance and distribution. The ability of the larger larvae to avoid slow-moving nets during the daylight hours has been previously demonstrated by Bowers (1952) and Bridger (1956) and is further evidenced by the greater average size of larvae caught in the recorder than those caught in the metre net. Diurnal vertical movements of juvenile, immature, and mature herring have frequently been observed on both sides of the Atlantic (Moore, 1898; Lucas, 1936; Johnson, 1939; and Richardson, 1952). Diurnal changes in the depth of larval herring, however, have not been

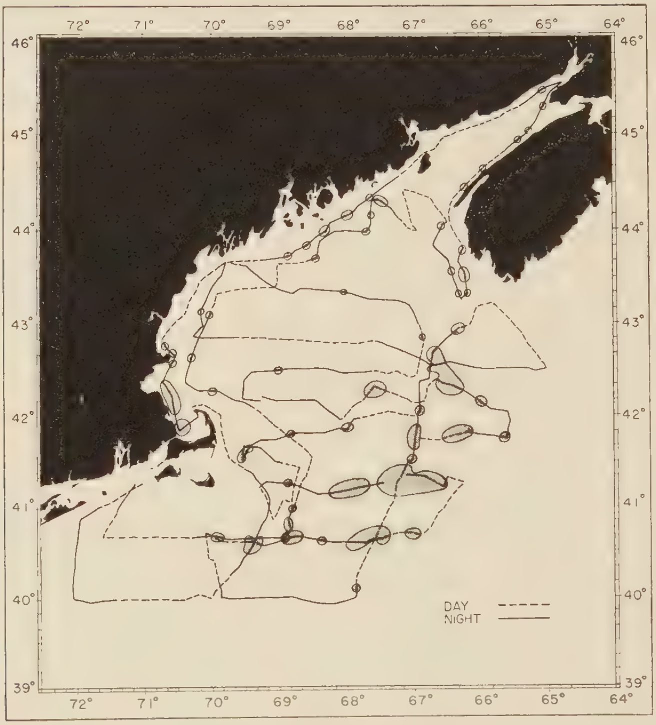


Figure 8. Day and night distribution of larval herring, November 1956, and February 1957.

conclusively demonstrated although BRIDGER (1958) on the basis of horizontal tows at 4, 10, and 17 fms with a modified Gulf III high-speed tow net showed that in full daylight the bottom yielded a higher proportion of older postlarvae (16–25 mm).

The effect of escapement and diurnal migrations upon the distribution pattern as determined by metre-net and recorder sampling in the upper 10 m of water is clearly shown in Figure 8. Here the plot of the distribution of herring larvae during November 1956, and February 1957, is superimposed on a track chart showing the periods of daylight (sunrise to sunset) and darkness (sunset to sunrise). With only a few exceptions, all catches of larval herring were made at night or within a few hours after sunrise. What is plotted is not a picture of the distribution over the whole area, but of the distribution at night. Herring most likely occurred in many areas other than those indicated.

The data suggest that in order to sample larvel herring effectively it is necessary to employ high-speed nets. Of the two sampling methods used, the Hardy Plankton Recorder, because of its high speed and continuity of tow, gives the better estimate of abundance and distribution. The magnitude of the recorder sample is not sufficient, however, for detailed analysis of growth and mortality. Secondly, the data indicate that the vertical distribution of larval herring changes during the day and night and that the depth of maximum abundance is below the depth sampled during these cruises (10 m).

BRIDGER (1958) overcame these two limitations through the use of oblique Gulf III tow-net hauls and concluded that diurnal migration of postlarval herring is unlikely to affect their capture provided that the oblique haul is made to within 2 fms of the sea bed. Although it appears that in relatively shoal water oblique high-speed tows would be a more suitable sampling method, it will be first necessary to determine accurately the depth distribution of larval and postlarval herring over the whole water column and the extent of their diurnal vertical migrations. For such a study it is essential to use high-speed samplers that can be towed in series down to considerable depths (100 m) and that filter enough water to give samples of sufficient size for statistical analysis. Such a programme of study is now being undertaken at this laboratory.

Summary

1. An analysis was made of metre-net and Hardy Plankton Recorder tows used in the study of the distribution and abundance of larval herring in the Gulf of Maine.
2. A greater average abundance of larval herring and a more detailed picture of distribution was indicated by the Hardy Plankton Recorder data than by the metre-net collections.
3. The ratio of the number of larvae per cubic metre caught in the Hardy Plankton Recorder to that caught in the metre-net increased with an increase in the length of the larvae.
4. The average length of larvae taken in the Recorder was greater than the average length of larvae caught in metre-net tows, and this variation was shown to be due to escapement of the larger larvae from the metre net during the daylight hours.
5. The number and average length of larval herring and red hake were greater at night in the metre-net catches, while the number and length of herring larvae but not red hake were greater at night recorder catches. Thus, differences in the day and night catch of larval herring are not due solely to daytime escapement of the larger larvae, but also to the fact that larval herring move up to the surface layers during the night.
6. In the recorder more larval herring were caught at 10 m than at the surface during both the day and night and there was an increase in the night/day ratio with an increase in larval size. These observations indicate that the depth of maximum abundance of larval herring is below 10 m and that the extent of diurnal migration increases with an increase in the size of the larvae.
7. It is demonstrated that a true picture of the distribution of larval herring is not obtained by either the metre-net or the Hardy Plankton Recorder samples when such sampling is confined to the upper 10 m of water.

References

BOWERS, A. B., 1952. "Studies on the herring (*Clupea harengus* L.) in Manx waters: The autumn spawning, and larval and post-larval stages." Proc. Trans. Liverpool Biol. Soc., **58**: 47–74.

BRIDGER, J. P., 1956. "On day and night variations in catches of fish larvae." J. Cons. int. Explor. Mer, **22**: 42–57.

BRIDGER, J. P., 1958. "On efficiency tests made with a modified Gulf III high-speed townet." J. Cons. int. Explor. Mer, **23**: 357–65.

HARDY, A. C., 1936. "The continuous plankton recorder." Discovery Rep., **11**: 457–510.

HUBBS, C. L., 1943. "Terminology of early stages of fishes." Copeia, No. 4: 260.

JOHNSON, W. H., 1939. "Effect of light on movements of herring". J. Fish. Res. Bd. Can., **4**: 349–54.

LUCAS, C. E., 1936. "On diurnal variation of size groups of trawl caught herring". J. Cons. int. Explor. Mer, **11**: 53–59.

MOORE, H. F., 1898. "Observations on the herring and herring fisheries of the north-east coast, with special reference to the vicinity of Passamaquoddy Bay". Rep. U. S. Fish. Comm., **22**: 387–442.

RICHARDSON, I. D., 1952. "Some reactions of pelagic fish to light as recorded by echo sounding". Fish. Invest., Lond., Ser. 2, **18** (1): 1–20.

TIBBO, S. N., LEGARÉ, J. E. Henri, SCATTERGOOD, L. W., & TEMPLE, R. F., 1958. "On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine". J. Fish. Res. Bd. Can., **15**: 1451–69.

ANDELSBOGTRYKKERIET I ODENSE

24

THE ENIGMA OF GEORGES BANK SPAWNING

BY JOHN B. COLTON, JR., AND ROBERT F. TEMPLE

Made in United States of America
Reprinted from LIMNOLOGY AND OCEANOGRAPHY
Vol. 6, No. 3, July, 1961
pp. 280–291

Made in United States of America
Reprinted from Limnology and Oceanography
Vol. 6, No. 3, July, 1961
pp. 280–291

THE ENIGMA OF GEORGES BANK SPAWNING

by John B. Colton, Jr., and Robert F. Temple

THE ENIGMA OF GEORGES BANK SPAWNING

John B. Colton, Jr., and Robert F. Temple
U. S. Bureau of Commercial Fisheries, Boothbay Harbor, Maine

ABSTRACT

The drift of bottles and transponding drift buoys over the Georges Bank area show that, with the exception of midsummer when the Georges eddy is most pronounced and southerly winds predominate, surface drift is offshore in the direction of the slope water band. Indications are that the currents below the surface move at a slower rate than at the surface, but in a similar direction. The effects of offshore drift, time and location of spawning, vertical distribution of eggs and larvae, and length of pelagic life on the dispersal and survival of eggs, larvae, and juveniles of commercially important foodfishes are discussed. It appears from observations on haddock and herring that under average conditions most fish eggs and larvae are carried away from Georges Bank and lost to the fishery, that only under unusual hydrographic conditions are the eggs and larvae retained in the area, and that the year class strength of the various species inhabiting Georges Bank is dependent in part upon non-tidal drift.

INTRODUCTION

The Georges Bank area, because of its tremendous productivity resulting from strong tidal stirring, is a favorite habitat of many demersal and pelagic species of fish. Georges Bank not only is one of the most productive fishing grounds in the North Atlantic, but also is the principal spawning area for many species of fish and shellfish. Some of the commercially important species that spawn there are haddock (*Melanogrammus aeglefinus*), cod (*Gadus callarias*), pollock (*Pollachius virens*), whiting (*Merluccius bilinearis*), red hake (*Urophycis chuss*), cusk (*Brosme brosme*), herring (*Clupea harengus*), American dab (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*), gray sole (*Glyptocephalus cynoglossus*), and the sea scallop (*Placopecten magellanicus*). The approximate times of maximum spawning for these species on Georges Bank are as follows: pollock, December–February; cod, January–March; gray sole, January–April; haddock, February–April; American plaice, March–May; cusk, April–May; whiting and yellowtail, May–July; red hake, June–September; and herring and sea scallop, September–October.

All these fish are bottom spawners, but the larvae of all species and the eggs of all species except herring drift passively in the upper water layers for considerable periods after spawning. In view of the non-tidal circulation pattern as deduced from drift-bottle, and transponding drift-buoy studies, and of the proximity of Georges Bank to the easterly flowing band of slope water, it is somewhat puzzling as to how these populations of fish maintain themselves in the area. It is the purpose of this paper to illustrate the effect of non-tidal drift upon the dispersal of eggs and larvae from Georges Bank using data collected during the haddock and herring spawning seasons and to discuss the consequence of physical and biological factors upon the abundance of the various species of fish inhabiting the Georges Bank area.

SOURCES OF MATERIAL

The data on haddock spawning and the distribution and drift of haddock eggs and larvae are based on collections made by the U. S. Fish and Wildlife Service during the spring months of 1953, 1955, 1956, and 1957 (*Albatross III* cruises 46, 48, 57, 58, 60, 71, 72, 73, 90, 92, 93, 94, and 95) as part of a program designed to study the early life history of haddock. The authors are particularly indebted to Messrs. Robert R. Marak and David Miller of the U. S. Fish and Wildlife Service Biological Laboratory, Woods Hole, Mass., for assistance in the collection and processing of these data. Data on the spawning location of herring are based on collections made by the U. S. Fish and Wildlife Service and the Fisheries Research Board of Canada during the fall months of 1956 and 1957 (*Silver Bay* cruises 1 and 2, and *Haren-*

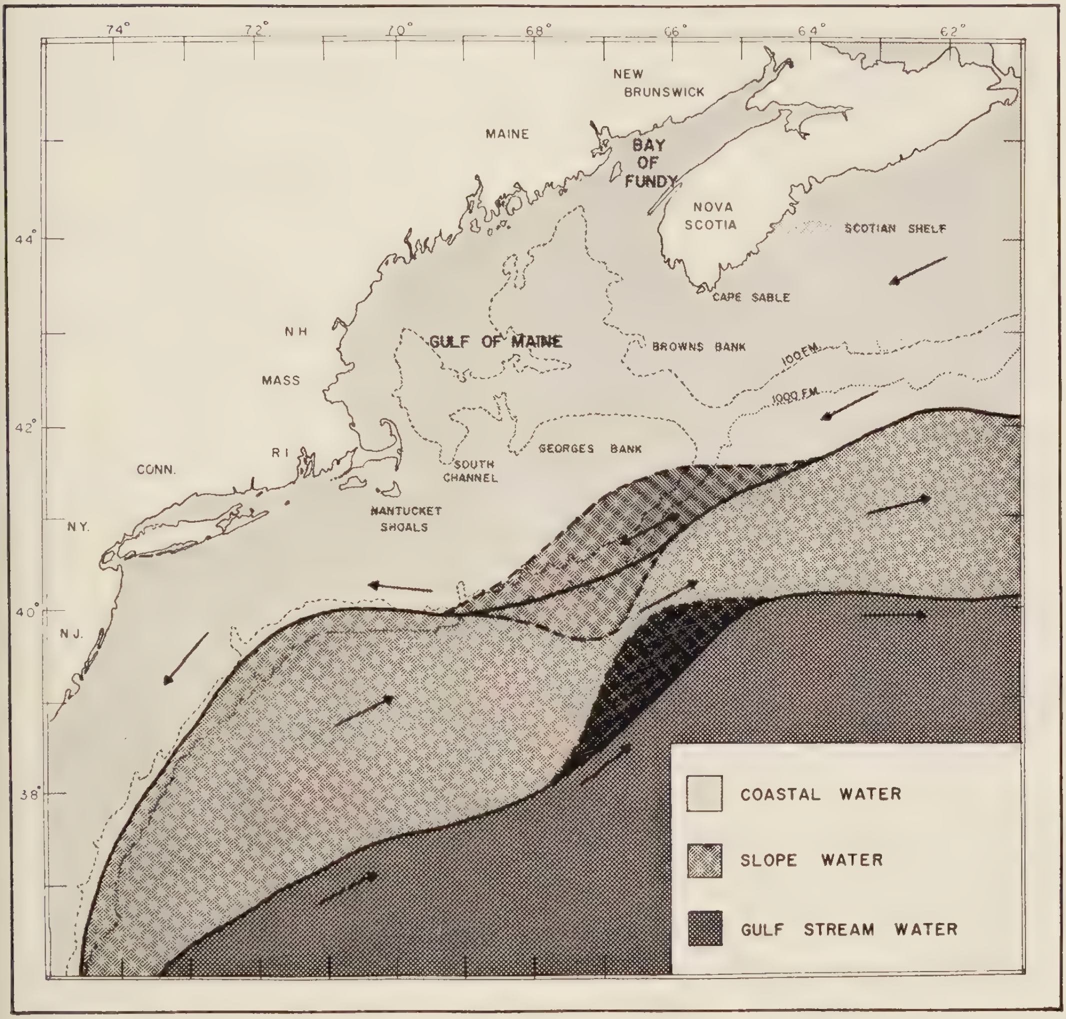

74°
72°
70°
68°
66°
64°
62°
44°
42°
40°
38°
NEW BRUNSWICK
MAINE
BAY OF FUNDY
NOVA SCOTIA
SCOTIAN SHELF
CAPE SABLE
N H
MASS
GULF OF MAINE
BROWNS BANK
100 FM
1000 FM
R I
CONN.
GEORGES BANK
SOUTH CHANNEL
NANTUCKET SHOALS
N.Y.
N.J.
COASTAL WATER
SLOPE WATER
GULF STREAM WATER

FIG. 1. Diagrammatic representation of the areal extent and movement of coastal, slope, and Gulf Stream water off the coast of Nova Scotia and New England.

gus cruises 5, 6, 17, and 18) as part of a program designed to study the early life history of herring.

Cruises during both these programs were of approximately 2 weeks' duration and the area of coverage included the Bay of Fundy, Gulf of Maine, Browns Bank, and Georges Bank. During these cruises Hardy Plankton Recorders (Hardy 1936) were towed continuously at the surface and 10 m; and 15-min surface and oblique (10 m) meter-net tows, bathythermograph lowerings, surface salinity samples, and drift bottle releases were made at specified stations. The drift bottles were of 8-fluid-ounce capacity. Twelve bottles were released at each station, 6 with sand ballast and 6 without. Drift-bottle data were processed under contract with the Woods Hole Oceanographic Institution under the direction of Mr. Dean F. Bumpus.

GENERAL HYDROGRAPHY OF COASTAL AND OFFSHORE WATERS OF NEW ENGLAND AND NOVA SCOTIA

In sequence from the coast of New England and Nova Scotia there are three distinct bands of water having well-defined temperature and salinity characteristics. They are the relatively cool and less saline (<35‰) *coastal water* covering the continental shelf and often extending near the surface well beyond the 100-fathom contour; the *slope water* having intermediate values of temperature and salinity (35–36‰); and the *Gulf Stream* water of relatively high temperature and salinity (>36‰) (Iselin 1936). The transition from one zone to the next is rapid, with considerable variations in temperature and salinity taking place within a very few miles. The general topography of the area under discussion and a diagrammatic representation of these three oceanographic regions are given in Figure 1.

The slope water, which lies between the coastal water having a southwesterly drift and the Gulf Stream moving swiftly towards the northeast, is a mixing zone for coastal water which has escaped over the continental shelf and Gulf Stream water which has been carried north of the current's path (Iselin 1936). A regular feature of the slope water is an easterly flowing current, the energy for which comes from a frictional drag when momentum is transferred across the northern edge of the Gulf Stream (McLellan 1957). This slope water band extends southwest only as far as Cape Hatteras.

There are marked flucuations in the relative position and areal extent of the three water masses in time and space (Fig. 1). Slope water has frequently been observed to overflow onto Georges Bank; coastal and Gulf Stream water meet at times off the southern edge of Georges Bank; cold patches of coastal water sometimes occur along the northern edge of the Gulf Stream; and eddies of warm Gulf Stream water are from time to time thrown off into the slope water (McLellan 1957).

The discharge of land drainage into the coastal water maintains a lower salinity and density in the surface layer there than in the surface layer offshore. The hydrostatic forces tend to drive this surface layer offshore and this, coupled with the Coriolis acceleration, results in a southwesterly flow along the shelf (McLellan 1957). Tidal currents, bottom topography, river runoff, and winds tend to disrupt the general southwesterly drift of coastal water along the continental shelf, and the circulation pattern in an area such as the Gulf of Maine is quite complex. The dominant non-tidal circulation of the Gulf of Maine as described by Bigelow (1927) and shown schematically in Figure 2 comprises a general counterclockwise eddy around the basin of the Gulf with an indraft on the southern side of the Bay of Fundy along the Nova Scotian shore, a separation of the outflow of the Gulf to the south, and an easterly drift along the northern side of Georges Bank, the latter being the center of a clockwise eddy. The average rate of surface drift is in the order of 3–4 miles per day. Recent drift-bottle studies (Day 1958, Bumpus 1958 and 1960) reveal that Bigelow's July–August pattern showing a relatively closed circulation seems to evolve with the seasons as a result of vernal warming and the consequent formation of density structure. These studies show that during February and March the Gulf eddy is ill-defined and there is a strong movement of water southward out of the South Channel. By late April the two counterrotating eddies begin to build up with the appearance of a northeasterly drift along the northern edge

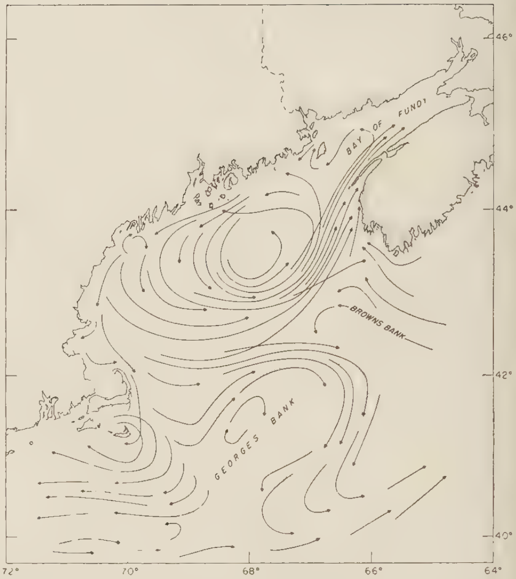


FIG. 2. Schematic representation of the dominant non-tidal circulation of the Gulf of Maine, July to August. (After Bigelow.)

of Georges Bank where the two eddies become confluent. The dual-eddy system continues throughout the summer, but by early fall the Georges eddy and the southern side of the Gulf eddy begin to weaken and the indraft into the Bay of Fundy is limited to north of 43° N. In winter the western side of the Gulf eddy weakens and the Georges eddy gives way to an easterly offshore drift. At this time the density of the waters over the continental shelf becomes more like that of the corresponding layer beyond the 100-fathom curve, coastal currents die away, and the predominantly northwest winds force large masses of water offshore. There is no evidence from drift-bottle work of any movement across Georges Bank from south to north, although surface water occasionally drifts northward from the continental shelf to the west of Nantucket Shoals during the late summer.

HADDOCK-SPAWNING AREAS AND THE DRIFT OF BOTTLES AND TRANSPONDING DRIFT BUOYS

The spawning areas of haddock were determined from the distribution of early-stage eggs caught in meter-net and Hardy Plankton Recorder tows. The period of embryonic development included is from fertilization to the approach of the germinal ring to an equatorial position. At the prevailing water temperatures on Georges Bank during the spawning period (40° to 44°F) this grouping includes eggs up to 8 days old. The locations of appreciable haddock spawning and of drift-bottle releases and the percentage recovery of drift bottles along the shoreline between Cape Sable, Nova Scotia (43°30′ N, 65°30′ W) and Normandy Beach, New Jersey (40°00′ N, 74°04′ W) are shown in Figures 3, 4, and 5. Only drift-bottle returns within this area have been considered in determining percentage recovery, as there is no evidence that larval fish carried beyond this area return to the Gulf of Maine as juvenile or adult fish.

In all years the distribution of early-stage eggs revealed that Georges Bank and Browns Bank were the principal spawning areas for haddock. Limited spawning oc-

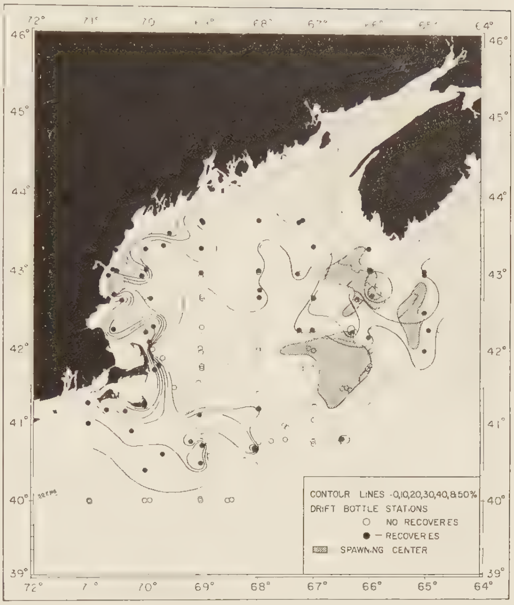


FIG. 3. Haddock spawning locations, drift-bottle release stations, and percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., *Albatross III* cruises 46 and 48, March 19–April 2 and April 24–May 8, 1953.

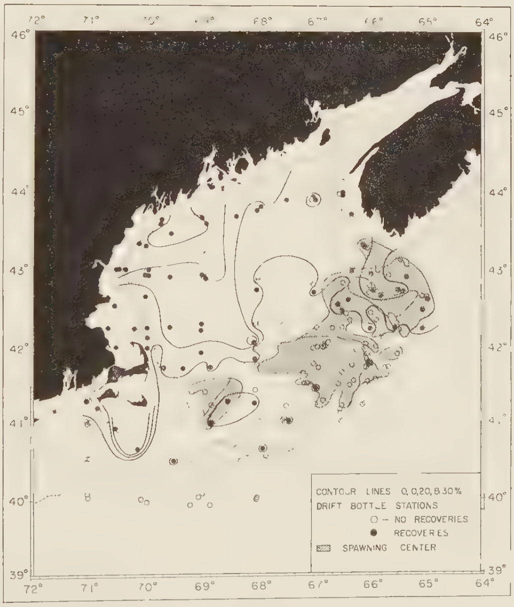


FIG. 4. Haddock spawning locations, drift-bottle release stations, and percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., *Albatross III* cruises 57, 58, and 60, February 21–March 2, March 19–April 1, and April 19–May 3, 1955.

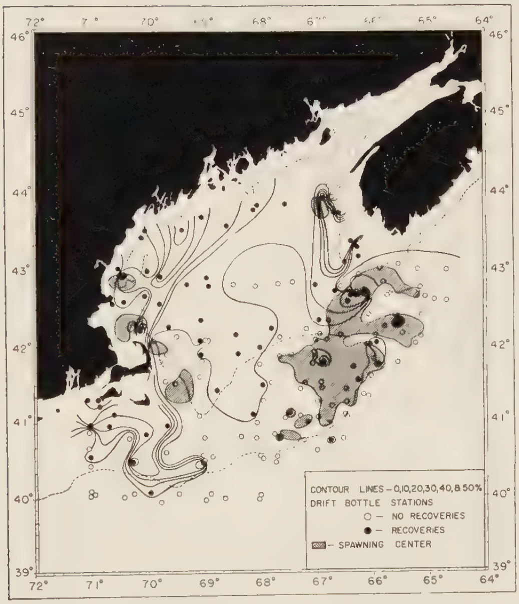


FIG. 5. Haddock spawning locations, drift-bottle release stations, and percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., *Albatross III* cruises 71, 72, and 73, February 20–March 2, March 21–31, and April 17–28, 1956.

curred in the South Channel and along the New England coast. These spawning locations coincide with those depicted by Walford (1938). With the exception of 1955 the total production as indicated by the average number of eggs/m^3 in the upper 10 m of water was greater on Georges Bank than on Browns Bank. In all years Georges Bank spawning occurred in an area of minimum drift-bottle returns. Drift bottles released on Georges Bank tended to drift southwesterly and out of the area. The majority of the meager recoveries from the areas of spawning were from the coastline between New Jersey and Cape Hatteras and from foreign shores. Most of the locations in which spawning occurred in the Browns Bank area coincided with areas from which there was a relatively high percentage of drift-bottle recoveries. Bottles released on Browns Bank and off southwestern Nova Scotia tended to drift northwesterly and beach along the shores of western Nova Scotia, New Brunswick, and New England as far south as Cape Cod (Day 1958). Surface drift during the haddock-spawning season as indicated by drift-bottle data is offshore over Georges Bank and inshore over Browns Bank. Plots of the relative distribution of eggs and of larvae, assumed to have hatched from these eggs, showed a similar southwesterly drift over Georges Bank and a northwesterly drift from Browns Bank.

Although it has been possible in each year to demonstrate a southerly movement of haddock eggs and larvae from the Georges Bank spawning center, neither eggs nor larvae were ever found off the southern edge of the Bank in the slope water band. Drift-bottle data indicate such a drift, but furnish no information as to the actual trajectory of the bottle between the place of launching and recovery. In order to obtain more detailed information on the movement of surface water over Georges Bank, transponding drift buoys were set out in a concentration of haddock eggs and their drift observed during April, May, and June, 1957. The details of the transponding drift buoys used in this work have been described by Bumpus, *et al.* (1957). The buoys were 20 ft long, 6 in. in diameter, and ballasted to float vertically with 2 ft of freeboard surmounted with a 13-ft whip antenna. When the buoy's receiver was energized by a tone-modulated signal from the *Albatross III*, the buoy's transmitter responded with signals which in turn were homed on by the vessel's radio direction finder. Repetition of this procedure and suitable maneuvering of the vessel brought the buoy within visual range.

Concentrations of early-stage haddock eggs were located by means of meter-net and Hardy Plankton Recorder tows, and transponding drift buoys were released in the area of maximum spawning. The transponding drift buoys used in this study were named *Mike*, *India*, *November*, and *Hotel*. The location of haddock spawning and of drift-bottle releases between April 2 and May 16 and of transponding drift-buoy releases between April 15 and May 23, the percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., and the drift of transponding drift buoys are shown in Figure 6.

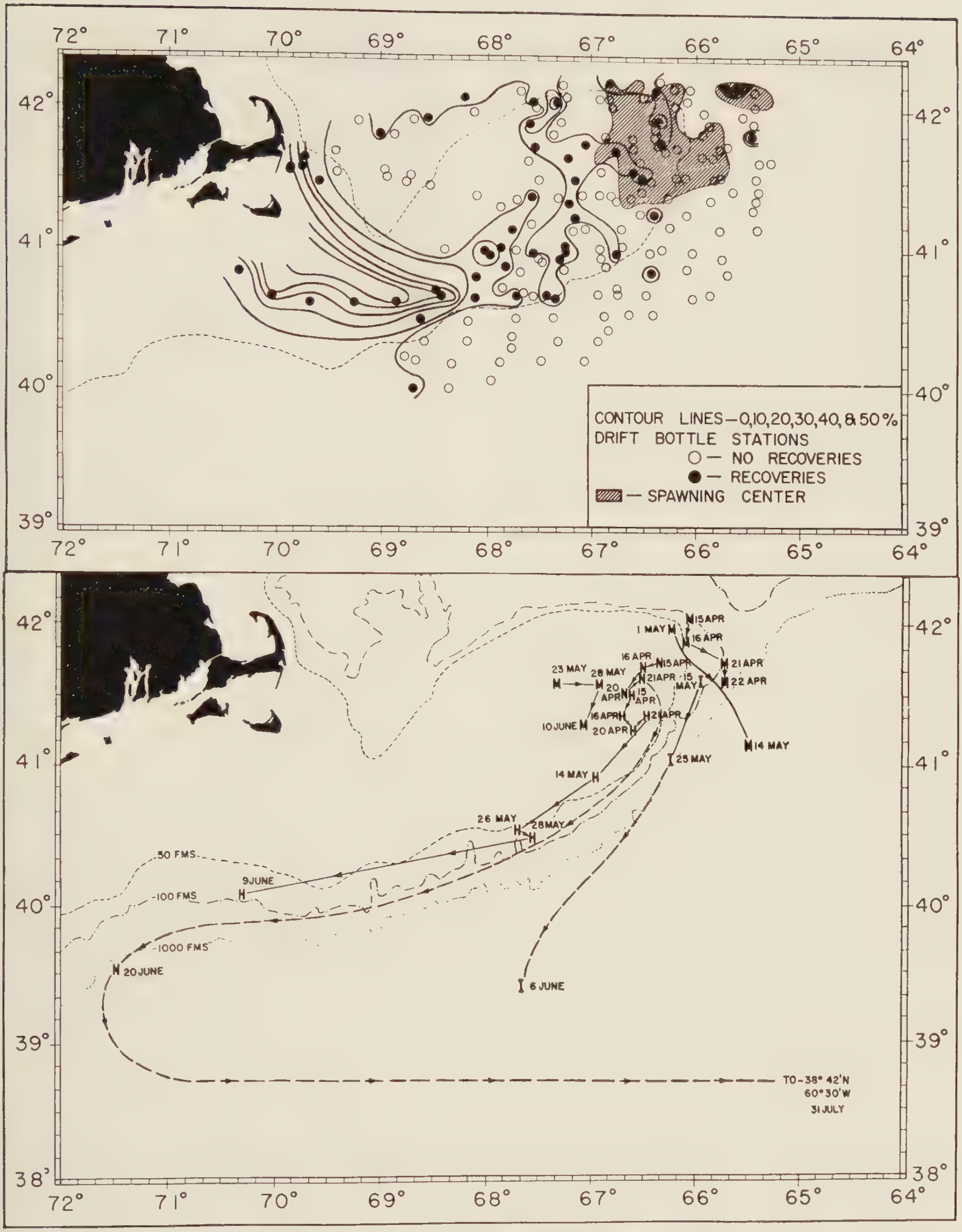

72°
71°
70°
69°
68°
67°
66°
65°
64°
42°
41°
40°
39°
38°
CONTOUR LINES—0,10,20,30,40, & 50%
DRIFT BOTTLE STATIONS
○ — NO RECOVERIES
● — RECOVERIES
▨ — SPAWNING CENTER
15 APR
1 MAY
16 APR
21 APR
22 APR
16 APR
15 APR
23 MAY
28 MAY
21 APR
15 MAY
20 APR
15 APR
16 APR
21 APR
10 JUNE
20 APR
14 MAY
25 MAY
14 MAY
26 MAY
28 MAY
50 FMS.
9 JUNE
100 FMS
1000 FMS
20 JUNE
6 JUNE
TO—38° 42′N
60° 30′W
31 JULY

FIG. 6. Haddock spawning locations, drift-bottle and transponding drift-buoy release stations, percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., and transponding buoy drift, *Albatross III* cruises 90, 92, 93, 94, and 95, April 12–17, April 25–May 2, May 8–16, May 22–29, and June 5–12, 1957.

Buoys set out at the northeast part of Georges Bank (*Mike* and *India*) moved southerly into deep water at velocities greater than 5 miles/day. Buoy *Hotel* moved slowly (approximately 1.5 miles/day) in a southwesterly direction until May 28 and then drifted rapidly (approximately 10 miles/day) in a west southwesterly direction. Buoy *November*, which failed to respond after April 21, was sighted on June 20 just east of the Hudson Canyon, after having probably moved along a similar course as *Hotel*. Buoy *November* was subsequently sighted in the Gulf Stream on July 31, 500 miles to the eastward of its June 20 position. The drift of the transponding drift buoys substantiates the previously noted clockwise circulation around Georges Bank (Fig. 2) but what is more important it also conclusively demonstrates a southerly movement of surface water away from the area of spawning on Georges Bank and out into the slope water band.

In contrast to previous years, considerable numbers of bottles released on Georges Bank in 1957 were recovered. Most of these bottles beached along the southern shore of Cape Cod and on Nantucket and Martha's Vineyard. However, a few bottles set out in the area of transponding drift-buoy release stations on the northeast part of Georges Bank moved in a northerly direction and were recovered along the coasts of Nova Scotia and New Brunswick. This suggests a differential drift between surface and depth and that the drift bottles, which float in the upper few feet of water compared to the 18-ft draft of the transponding drift buoys, were more subject to the predominantly southwesterly wind conditions existing at this time. It appears that bottle drift is not always a reliable indication of the dominant non-tidal circulation.

The movement of the transponding drift buoys and bottles indicates that at this time of the year the non-tidal circulation over Georges Bank is such that eggs and larvae in the surface layers would be carried out into the slope water zone or into the coastal waters west of Cape Cod.

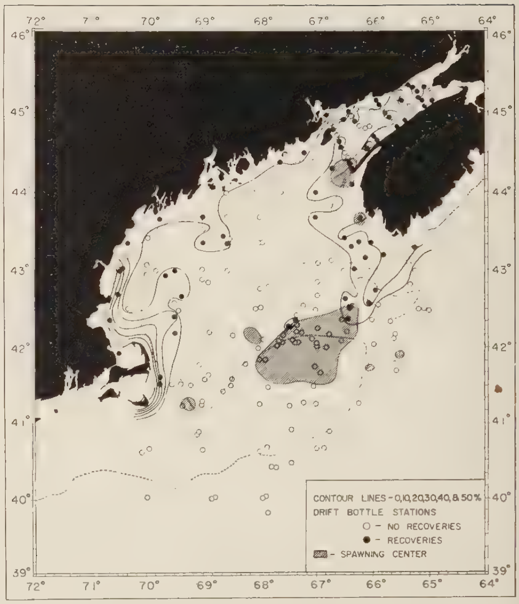


FIG. 7. Herring spawning locations, drift-bottle release stations, and percentage drift-bottle recovery between Cape Sable, N. S., and Normandy Beach, N. J., *Silver Bay* cruises 1 and 2, September 21–October 5, and October 15–25, 1956, *Harengus* cruises AH5, AH6, 17, and 18, September 19–October 4 and October 16–November 8, 1956, September 9–26 and October 7–25, 1957, and *Albatross III* cruise 104, October 9–17, 1957.

HERRING-SPAWNING AREAS AND THE DRIFT OF BOTTLES AND TRANSPONDING DRIFT BUOYS

The location of spawning areas of herring is based on the distribution of 5- to 7-mm larvae as determined from meter-net and Hardy Plankton Recorder tows during September and October, 1956 and 1957. This length range approximates the range in hatching size of larval herring and in the absence of egg samples from the bottom affords the best available approximation of spawning location. The location of appreciable spawning and of drift-bottle releases, and the percentage recovery of drift bottles
Beach, N. J., are shown in Figure 7.
between Cape Sable, N. S., and Normandy

The main area of spawning indicated by the distribution of newly hatched larvae was along the northern edge of Georges Bank. Limited spawning occurred off the west coast of Nova Scotia and in the South Channel. Herring may also have spawned to some extent in shoal water areas along the coast of Nova Scotia, New Brunswick, and Maine not covered in these surveys. However, the magnitude of production, as indicated by the number of larvae/m^3 in the upper 10 m of water, was so much greater over Georges Bank than in other areas that it is evident this is the principal fall spawning area in the Gulf of Maine.[1] Spawning also occurs in the Fundy region during the spring, but it is very light and very much less in importance than the heavy autumn spawning (Tibbo, *et al.* 1958).

As with haddock, herring spawned on Georges Bank in an area of minimum drift-bottle returns. The areal extent of the stations from which there were no drift-bottle recoveries was considerably greater than it was during the spring months. It was only from stations along the coast and over Browns Bank that recoveries were made. Transponding drift buoys released over the western part of Georges Bank during October and December, 1957, moved in an easterly direction at speeds of approximately 7 miles/day (Bumpus 1958). The dominant easterly offshore drift of buoys and the almost complete void of local drift-bottle returns from the Gulf of Maine and Georges Bank show that during the autumn and winter the dual-eddy system breaks down and the Georges eddy gives way to an easterly offshore drift.

The non-tidal circulation over Georges Bank during herring spawning differed markedly from that during haddock spawning. In the spring the net surface movement across Georges Bank was southerly and southwesterly, while in the fall the net surface movement was easterly. Herring larvae in the surface layers over Georges Bank would have been carried more rapidly out into deep water than haddock eggs and larvae. It appears that herring larvae had less chance of being retained in the area or of being carried into the Gulf of Maine and the Bay of Fundy than did haddock larvae.

DISCUSSION

Data on the drift of bottles and on the movement of transponding drift buoys show that, with the exception of midsummer when the Georges eddy is most pronounced and southerly winds predominate, surface drift over the Georges Bank area is offshore in the direction of the slope water band. It appears, therefore, that at most seasons of the year fish eggs and larvae in the surface layers would be carried away from Georges Bank and lost to the fishery. However, before we can conclude that this is the fate of the majority of eggs and larvae produced on Georges Bank, we must consider the differential rate and direction of drift between surface and depth, the vertical distribution of eggs and larvae, the effect of the warm slope water on survival, the length of pelagic life, and the ability of larval and juvenile fish to move independently of the existing currents.

Surprisingly little is known about the subsurface currents in the Georges Bank–Gulf of Maine area. Most of the information available is based on inferences from temperature and salinity observations (Bigelow 1927), and the only extensive direct current measurements made in the area have been surface observations. Strong tidal mixing over most of the area keeps the water mixed from top to bottom, so that little vertical stability develops even in the warmest months. Strong temperature and density gradients are usually found only along the edge of the continental shelf and in isolated bays along the coast. The distribution of temperature and salinity suggests that in general the circulation pattern deduced from surface observations is effective to at least 100 m although the velocities are somewhat lower in the deeper water than at the surface. With increasing depth, however, the direction of flow is more and more influenced by the contour of the bottom. Wind currents which may accentuate or weaken the prevailing drift or at times cause the surface water to move in a different direction than subsurface water are confined to the upper 10 to 20 m of the water column.

---

[1] It is of interest to note that only during the fall spawning season do otter trawlers capture appreciable numbers of herring over Georges Bank; little is known about the distribution of these Georges Bank fish at other seasons of the year.

Ballasted drift bottles which sank and were picked up on the bottom or at mid-depths by fishermen showed a uniform southwesterly movement along the southern part of Georges Bank and a general southerly movement out of the South Channel (Day 1958). The rate of drift of these bottles was considerably less than that of bottles which remained at the surface. Experiments in which buoys have been rigged with parachute drogues of varying lengths also showed that in general the direction of flow was similar at depth, but that the rate of drift decreased with an increase in the depth of the drogue (Bumpus 1958).

Along the southern edge of Georges Bank, in the deeper parts of the Gulf of Maine Basin, and in the Eastern Channel, which separates Georges and Browns banks, the direction of water movement sometimes differs from that in the surface layers. From late summer through early spring, slope water enters the Gulf of Maine in varying pulses along the bottom of the eastern side of the Eastern Channel. The outward flow of slope water is usually along the western side of the Eastern Channel (Bigelow 1927). The general tendency of movement along the bottom within the basin is northward along the Nova Scotian slope and veering through west to southwest across the basin towards the offing of Massachusetts Bay. It is only along the bottom of Eastern Channel and the southern edge of Georges Bank that eggs and larvae could drift in an opposite direction from those in the surface and intermediate layers.

Vertical distribution studies of larval and juvenile haddock made in the Georges Bank area in 1958 (*Albatross III* cruise 111) using specially designed high-speed samplers towed in series at depths of 0, 10, 20, 30, 40, 50, and 75 m showed that in all locations, depths, and times the maximum abundance of larval and juvenile haddock (5–30 mm) was in the upper 20 m of water. Very few haddock were caught at depths greater than 20 m and the larger postlarvae and juveniles tended to be concentrated in shoaler depths than the smaller larvae. Although haddock eggs are known to occur in the deeper water layers (Walford 1938), indications are that the abundance of haddock eggs also decreases with depth, for in all cruises made in 1953, 1955, 1956, and 1957 the vast majority of eggs were collected in the plankton recorder towed at the surface.

Conjectures concerning the vertical distribution of larval herring in the Georges Bank area are based on generalizations inferred from their distribution and abundance in the upper 10 m of water. During the surveys of 1956 and 1957 more larval herring were caught at 10 m than at the surface during both the day and night. The number and average length of herring larvae, but not of other species, were greater at the surface and 10 m during the night. Indications are that the depth of maximum abundance of larval herring is below 10 m, that larval herring move up towards the surface layers during the night, and that the extent of these diurnal migrations increases with an increase in the size of the larvae.

Little is known of the vertical distribution of the eggs and larvae of other species found in the area, but indications from these surveys are that the eggs of most species are concentrated in the upper 10 m of water, that gadoid larvae are more abundant in the surface layers (0–20 m) and that flatfish larvae tend to be more abundant below 20 m. Herring is the only species in which there were indications of diurnal vertical movements.

The presence of the slope water band off the southern edge of Georges Bank affects the survival of larval fish in two ways. Firstly, any larval fish drifting into this zone would be carried in a northeasterly direction away from Georges Bank and the continental shelf. Secondly, because of the marked differences in the temperature of coastal and slope water, it is possible that larval fish transported from one zone to the other would be subject to a temperature change beyond the range of their thermal tolerance. That temperatures in the slope water band are at times lethal to species of larval fish endemic to the Gulf of Maine–Georges Bank area is evidenced by observations of the mortality of yellowtail flounder and whiting (Colton 1959).

Estimates by Bigelow and Schroeder (1953) indicate that 3 months would be an average time for the duration of pelagic life for the species of fish mentioned in this paper. However, there is a variation in the length of pelagic life with species and possibly within species according to location and environmental conditions. More recent observations indicate that the young of some species of fish remain in the surface layers for considerably longer periods than previously expected. During the plankton recorder surveys of the Georges Bank area in 1953, 1955, 1956, and 1957, juvenile herring (40–60 mm) were frequently found in the surface layers in February, March, and April; and juvenile pollock, cod, and red hake were found as late as May and June. It was also observed that there was closer association of haddock and whiting with the common red jellyfish (*Cyanea*) as the fish grew larger. Haddock and whiting longer than 20 mm were never found in areas where *Cyanea* was not present. Other species including hake and cusk were also frequently found living under the bells of *Cyanea* and this association, which has been observed previously in both American and European waters (Damas 1909, Russell 1928, Bigelow and Schroeder 1953), has the effect of limiting their depth distribution to the surface layers and of extending the period in which these fish can be considered true members of the planktonic community and subject to involuntary drift.

Horizontal tows at 10-m depth intervals made in the Gulf of Maine during August and September, 1957 (*Albatross III* cruises 99 and 102), with an Isaacs-Kidd midwater trawl (Isaacs and Kidd 1953) modified to operate as an opening-closing net showed that juvenile haddock were still concentrated in the surface layers 5 or 6 months after the time of maximum spawning. The average size of these juvenile haddock was 105 mm and an analysis of their depth distribution in the upper 100 m revealed that over 90% of the fish occurred between 10 and 30 m, that the depth of maximum abundance was at 20 m during the day and night, and that over 90% of the positive tows were made in areas where *Cyanea* was present.

Bottom tows with an otter trawl in the same areas showed that there was a small overlap between the size of the fish on the bottom and those at middepth. The average size of juvenile haddock on the bottom was 125 mm. Indications are that juvenile haddock live in association with *Cyanea* throughout their pelagic life and begin to take to the bottom at a length of about 100 mm.

The ability of larval and juvenile fish to move independently increases with size and by the time the metamorphic period is completed and the young fish have assumed adult characteristics (juvenile stage) they are capable of undertaking fairly extensive migrations. The duration of the larval period varies with species, being considerably longer in the herring, for example, than in haddock. The approximate size at which the various species complete metamorphosis is as follows: herring—40 mm, gadoids—20 mm, American dab—30 mm, gray sole—45 mm, and yellowtail flounder—15 mm. Postlarvae of species such as herring, in which metamorphosis extends over a considerable period, are capable of greater independent movement than are the postlarvae of species that have a short larval life. With the exception of the flounders and herring, this ability for independent movement is nullified to a great extent by the fact that these movements are confined for the most part to areas in which *Cyanea* occurs. Even though the young fish can and do move independently, their net movement is controlled in part by the drift of *Cyanea* and thus their distribution is still dependent to some degree upon the non-tidal circulation. It appears then that the dispersal of the majority of species from the spawning areas on Georges Bank is controlled primarily by non-tidal drift, that this involuntary movement is in effect for a 4- or 5-month period, and that not until the juvenile fish reach the bottom do they begin to control their distribution. Such an extensive pelagic period is in agreement with the average drift rate of bottles and the distribution of young-of-the-year haddock on the bottom during the fall of the year.

Young-of-the-year haddock are rarely found on Georges Bank in the fall. The area of maximum abundance in most years in which bottom surveys were made was in deep water (over 90 fathoms) in the South Channel and the southwestern part of the Gulf of Maine. Young-of-the-year haddock were also found in other parts of the Gulf and on Browns Bank. Only in 1948 and 1950 were young-of-the-year haddock found west of Georges Bank when large concentrations occurred in shoal water (20–50 fathoms) off southern New England and Long Island (Colton 1955). The 1948 and 1950 year classes are two of the strongest broods of Georges Bank haddock which have occurred since the collection of such statistics was begun in 1928 (Chase 1955). The young fish found off southern New England and Long Island most likely migrated back to Georges Bank by the following spring, as few one-year or older haddock are ever caught west of Nantucket Shoals. It is postulated that in most years the abundance of Georges Bank haddock is dependent upon spawning taking place in other areas (principally Browns Bank) and that strong year classes occur in those years when the eggs and larvae are retained on Georges Bank or in the coastal waters off southern New England and Long Island. It is possible that some young haddock take to the bottom further south, but there is no evidence that this happens.

The herring fishery in the Gulf of Maine is principally a sardine fishery. One- and 2-year-old fish make up the bulk of the catch and the fishery is centered along the coast of Maine and New Brunswick. Considering the location of the fishery and the dominant non-tidal drift on Georges Bank during the herring-spawning season, it is doubtful that herring spawned on Georges Bank contribute to this fishery. It is possible that in some years strong easterly or southerly winds would alter the dominant circulation pattern, but in general, hydrographic conditions over Georges Bank during the fall of the year are even less favorable for the retention of larvae over Georges Bank or for a northerly drift into the Gulf of Maine than during the spring. Herring larvae that drift westerly from the Georges Bank area might migrate back up along the coast, but there is no evidence to support this. Population studies based on parasitological and serological methods (Sindermann 1959) support the above conclusions. Sindermann's studies suggest that the adult herring populations spawning on the Nova Scotian coast and on Georges Bank are distinguishable, that there is only limited intermixing between the two areas, and that the sardine-size herring populating the northwestern shore of the Gulf of Maine are more similar to Nova Scotian adults than to Georges Bank adults.

It is even more puzzling as to how some of the other species which inhabit Georges Bank maintain themselves in the area. Whiting and yellowtail flounder, for example, spawn principally along the southern edge of Georges Bank and it would seem that the eggs and larvae of these species would be even more susceptible to an offshore drift. The restricted movements of the sea scallop preclude any migration, its larvae are even less capable of independent movement than larval fish, and yet the abundance of sea scallops on Georges Bank is not subject to marked fluctuations and millions of pounds are landed year after year.

Until more detailed information is obtained, no more than generalizations can be made concerning the fate of eggs and larvae produced on Georges Bank. For example, Walford (1938) concluded, on the basis of the relative numbers and distribution of postlarval haddock on Georges Bank in the spring of 1931 and 1932, that the 1931 year class exceeded in abundance that of 1932. Subsequent landings of the commercial fleet however showed that neither year class was exceptionally strong and that the 1932 year class was slightly more abundant. Nevertheless, on the basis of existing data, it appears that under average conditions most fish eggs and larvae are carried away from Georges Bank in the direction of the slope water zone and it is only under exceptional hydrographic conditions that appreciable numbers of eggs and larvae are retained on the Bank or in nearby coastal areas. It is our feeling that egg production in the various species is always sufficient to produce a strong year class but, in general, mortalities of eggs and larvae due to drift and other factors are such that only a small percentage survive. Future work should be directed to obtain detailed information on wind conditions over Georges Bank (which appear to be a most important variable), the effect of wind on non-tidal drift, the differential rate of drift between surface and depth, the interchange of coastal and slope water along the southern edge of Georges Bank, the vertical distribution of eggs and larvae and its variation among species, the variation in the location and time of spawning and its relation to the dispersal of eggs and larvae, and the degree of association with *Cyanea* in the various species and its effect upon vertical distribution, length of pelagic life, and dispersal from the spawning areas.

REFERENCES

BIGELOW, H. B. 1927. Physical oceanography of the Gulf of Maine. Bull. U. S. Bur. Fish., **40**: 511–1027.

———, AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U. S. Fish Wildl. Serv., Fish. Bull., **74**: 1–577.

BUMPUS, D. F. 1958. Investigations of climate and oceanographic factors influencing the environment of fish. Ref. No. 58–45, September, 1958. Woods Hole Oceanographic Institution. (*Unpublished manuscript.*)

———. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Bd. Canada, **17**: 181–197.

———, J. CHASE, C. G. DAY, D. H. FRANTZ, D. D. KETCHUM, AND R. G. WALDEN. 1957. A new technique for studying nontidal drift with results of experiments off Gay Head, Mass., and in the Bay of Fundy. J. Fish. Res. Bd. Canada, **14**: 931–944.

CHASE, J. 1955. Winds and temperature in relation to brood-strength of Georges Bank haddock. J. Cons. Int. Explor. Mer, **28**: 17–24.

COLTON, J. B. 1955. Spring and summer distribution of haddock on Georges Bank. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. **156**: 1–65.

———. 1959. A field observation of mortality of marine fish larvae due to warming. Limnol. Oceanogr., **4**: 219–222.

DAMAS, D. 1909. Contribution a la Biologie des Gadides. Rapp. Cons. Int. Explor. Mer, **10**: 1–277.

DAY, C. G. 1958. Surface circulation in the Gulf of Maine as deduced from drift bottles. U. S. Fish and Wildl. Serv., Fish. Bull., **141**: 443–472.

HARDY, A. C. 1936. The continuous plankton recorder. Discovery Rept., **11**: 457–510.

ISAACS, J. D., AND L. W. KIDD. 1953. Isaacs-Kidd midwater trawl. SIO. Reference 53-3, January, 1953. Scripps Institution of Oceanography. (*Unpublished manuscript.*)

ISELIN, C. O'D. 1936. A study of the circulation of the western North Atlantic. Papers in Phys. Oceanogr. and Meteor., **4**: 1–101.

MCLELLAN, H. J. 1957. On the distinctness and origin of the slope water off the Scotian Shelf and its easterly flow south of the Grand Banks. J. Fish. Res. Bd. Canada, **14**: 213–239.

RUSSELL, F. S. 1928. The vertical distribution of marine macroplankton. VIII. Further observations on the diurnal behavior of the pelagic young of teleostean fishes in the Plymouth area. J. Mar. Biol. Ass. U.K., **15**: 829–850.

SINDERMANN, C. J. 1959. Population studies of herring using parasitological and serological methods. International Passamaquoddy Fisheries Board, Rept. to Int. Joint Comm., App. III, **4**: 1–15.

TIBBO, S. N., J. E. HENRI LEGARÉ, L. W. SCATTERGOOD, AND R. F. TEMPLE. 1958. On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. J. Fish. Res. Bd. Canada, **15**: 1451–1469.

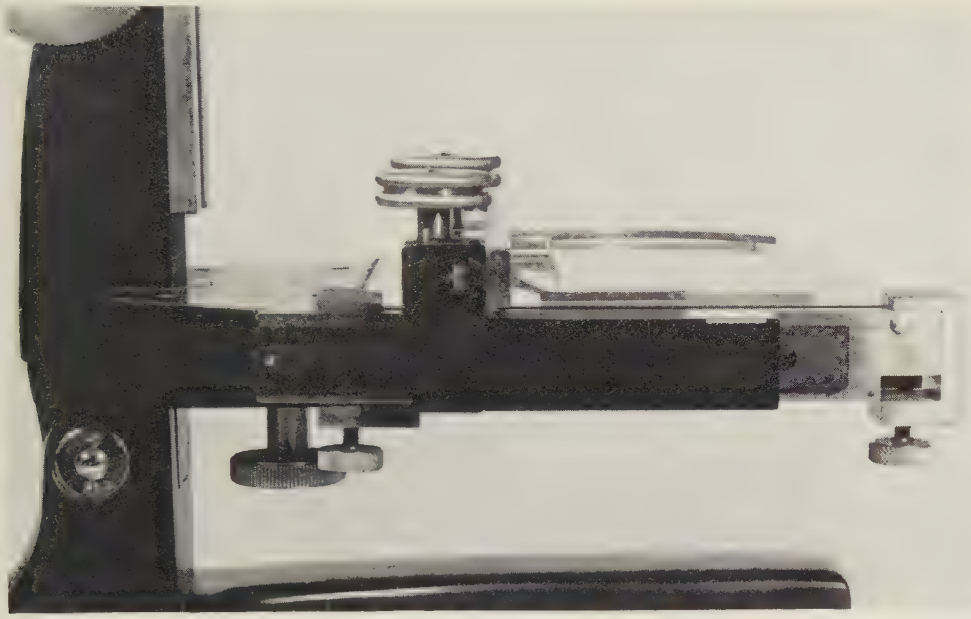
WALFORD, L. A. 1938. Effects of currents on the distribution and survival of eggs and larvae of haddock (*Melanogrammus aeglefinus*) on Georges Bank. Bull. U. S. Bur. Fish., **29**: 1–73.

25

Reprinted from COPEIA, 1961, No. 2, pp. 224-226, June 19
Printed in U. S. A.

A DEVICE FOR MEASURING LARVAL AND JUVENILE FISHES.—Many methods are used to measure larval, postlarval and juvenile fishes and usually require the use of ocular micrometers, dividers, calipers or dial calipers. In the case of cleared and stained fish, specimens are sometimes laid on a transparent plastic ruler and measurements read by transmitted light. All of these are time consuming and subject to inaccuracies.

During studies of early development of several fishes, a method of measuring larvae and juveniles which made use of a graduated mechanical stage was devised. By the use of this method accurate body measurements can be made to one tenth of



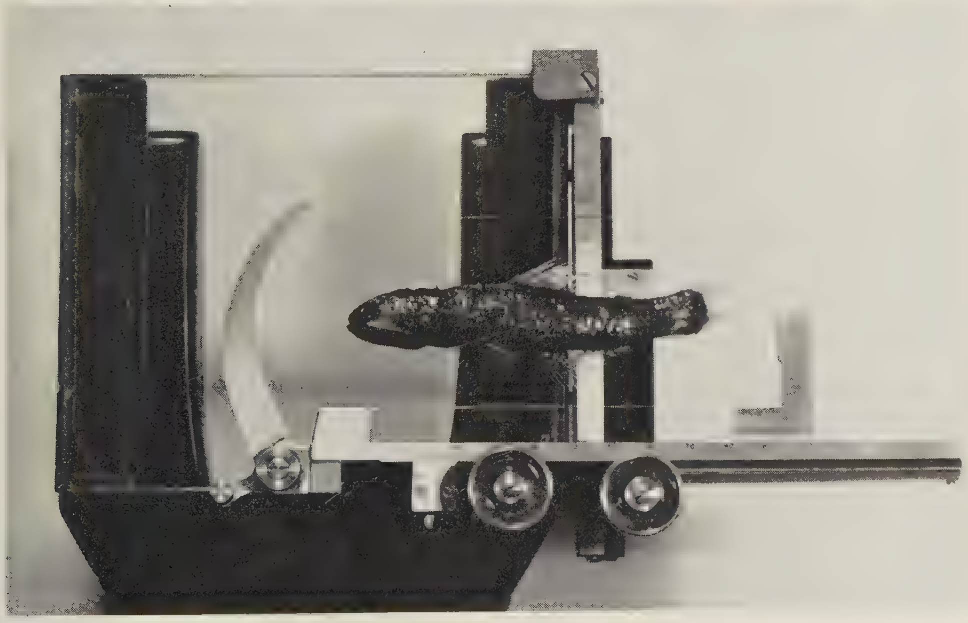


Fig. 1. Breed mechanical stage adopted to thick microscope stage in order to measure larval and juvenile fishes.
Fig. 2. Specimen on slide (microscope head removed) and scale set at zero to show the method of measuring a small fish

a millimeter on fish ranging in size from the smallest larva to a maximum standard length of 107 mm. No change in calibration is required with change in magnification as is necessary when using an ocular micrometer. Furthermore, the inherent inaccuracy of other methods, caused by relocating reference points after each measurement, is eliminated.

Materials.—Graduated mechanical stages are made primarily for compound research microscopes. They generally accommodate slides too short for use with specimens much longer than about 55 mm. A Breed mechanical stage (designed for making bacterial counts in milk) was finally selected as suitable for the purpose. This stage accommodates a sufficiently large standard slide (115 × 52 mm.) and is graduated in millimeters. Measurements can be read to tenths of a millimeter on a vernier scale.

Only one modification is needed on the mechanical stage. The original clamps, manufactured for the comparatively thin stage of a compound microscope, must be changed to suit the thicker stage of the dissecting microscope. New brass clamps, opening to 17.5 mm., were built (Fig. 1). The only necessary modification of the microscope is placement of a cross-hair disc in one of the oculars. Although the Breed 115 mm. standard slide is quite large, it was necessary to cut new slides to a length of 127 mm. in order to allow some excess space beyond the snout of the specimens when the stage was set at zero and the cross hair set at the tip of the snout. Aligning the specimen may be facilitated by etching or scribing a 5 mm. grid on the slide.

Methods.—To take a set of measurements, such as snout length, eye diameter, head length, snout to ventral fin, etc., the stage is first set at zero. The fish is placed on the slide, which is locked in the mechanical stage (Fig. 2). The microscope is focused on the snout and the fish moved to the zero position; i.e., the tip of the snout touches the center of the cross hairs in the field. At each point to be measured the microscope should be refocused because it may not be in the same plane as the previous point. The scale should be returned to zero to recheck the snout position before removing the fish. Often an array of measurements, e.g., snout length, head length, snout to dorsal, snout to anus, and standard length, can be taken rapidly from one zero setting with zero set at the snout. Subtractive procedures are necessary only where some particular measurement, such as eye diameter, is an interrupted part of a whole. Depths can be measured at pectoral, at caudal peduncle, etc. with the vertical scale.

In the case of a cleared and stained fish the specimen can be moved along smoothly to count vertebrae and fin rays. When measuring fish having a slight curl, the specimen may be pinned to a layer of cork glued on the slide.

Acknowledgments.—I wish to take this opportunity to thank Mr. Raymond M. Blei of the Special Developments section at Scripps Institution of Oceanography for machining the new stage clamps.—Robert C. Counts, *Biological Laboratory, U. S. Bureau of Commercial Fisheries, La Jolla, California. Published by permission of the Director, U. S. Bureal of Commercial Fisheries, Washington, D. C.*

In order to learn more about the route of the spring migration and to assist the industry in opening the season earlier, the California Department of Fish and Game for several years has fielded an exploratory survey of the offshore fishing grounds prior to the regular season. A cruise such as this was planned for the month of June 1959. The Honolulu Biological Laboratory, U.S. Bureau of Commercial Fisheries, was contemplating a similar survey of the west coast fishing grounds during the same period. Since the desired results were identical, final plans were made for a co-operative survey. Participation of two vessels promised far greater coverage of the area and collection of an increased amount of oceanographic data that might be useful in predicting future occurrences of albacore.

This report describes the fishing methods and resulting catch related to sea surface temperature for the cruises of both agencies. Another report will summarize the combined oceanographic observations (Graham and Craig, ms).

VESSELS AND INTINERARY

Assigned to the survey were the *N. B. Scofield* (Cruise 59S4) from the California Department of Fish and Game and the *Hugh M. Smith* (Cruise 52) from the Honolulu Biological Laboratory. The two vessels explored the offshore waters along 600 miles of the North American coastline from the latitude of Point San Eugenia, Baja California to the latitude of San Francisco.

The offshore waters of central and southern California were chosen for the *N. B. Scofield* survey from June 1 through June 25, 1959. The actual survey consisted of a series of lines running roughly northwest and southeast between the Mexican boundary and San Francisco and offshore as far as long. 128° W. (Figure 1).

The *Hugh M. Smith* survey was conducted south of the *N. B. Scofield,* primarily off the coast of northern Baja California, Mexico, and east of long. 125° W. The vessel sailed from Honolulu on April 28, 1959, first occupying a series of preliminary fishing and oceanographic stations between Honolulu and the mainland. The cruise terminated in San Diego on June 19, 1959 (Figure 1). An unscheduled interruption in the early portion of the survey was necessitated by the illness of a crew member who was taken to San Francisco for treatment.

FISHING GEAR AND METHODS

Trolling lines, longlines and gill nets were used in attempting to locate albacore schools. Live anchovies were carried for hook and line fishing, but actually were used only occasionally to chum the jig lines. Both vessels were equipped with similar fishing gear except that the *N. B. Scofield* carried no longlines.

The Honolulu Biological Laboratory cruise plan emphasized occupying a series of predetermined longline and gill net stations, with trolling between these stations. The Department of Fish and Game plan emphasized trolling, with the use of gill nets secondary.

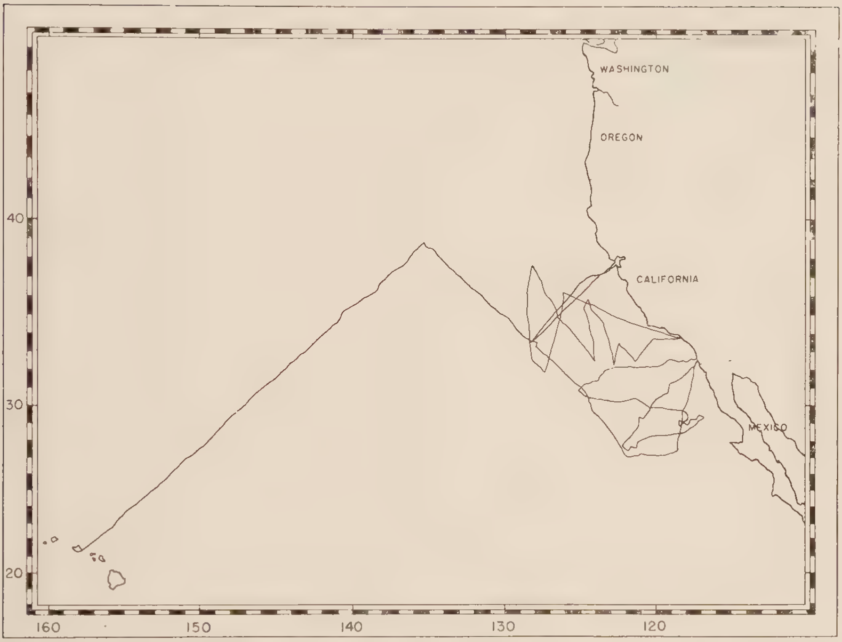


FIGURE 1. A portion of the eastern north Pacific Ocean illustrating schematically vessel tracks for the *N. B. Scofield* (Cruise 59S4) and *Hugh M. Smith* (Cruise 52) albacore survey, 1959.

Trolling Gear

The trolling gear was basically the same as that used by the commercial fleet (Scofield, 1956). Feathered japheads and bone jigs outfitted with barbless hooks were used on lines of varying length. Seven lines were trolled from the *N. B. Scofield*. These were arranged with a 20- and 15-fathom line on each outrigger pole and 7-, 9-, and 11-fathom lines fishing from the stern. The *Hugh M. Smith* trolled eight lines, two from each outrigger pole and four from the stern. Line lengths were alternately 15 and 30 fathoms (Figure 2).

Trolling was done during daylight at speeds ranging from 4 to 10 knots, but averaging six to seven.

Gill Nets

Both vessels were equipped with 10 shackles of nylon mesh gill net constructed by the Honolulu Biological Laboratory (Graham and Mann, 1959). Each shackle, 50 fathoms long by 4 deep, consisted of mesh sizes varying from $4\frac{1}{2}$ to $7\frac{1}{2}$ inches stretched measure. When setting from the vessel, shackles were arranged as follows: $4\frac{1}{2}''(1)$, $7\frac{1}{2}''(2)$, $6\frac{1}{2}''(4)$, $7\frac{1}{2}''(2)$ and $5\frac{1}{2}''(1)$.

Gill nets were set at dusk, the process requiring 30 to 60 minutes. Hauling took place at dawn the following day and required about one hour. The nets were set from the stern and hauled from the bow of the *N. B. Scofield*, and were both set and hauled from the bow of the *Hugh M. Smith*.

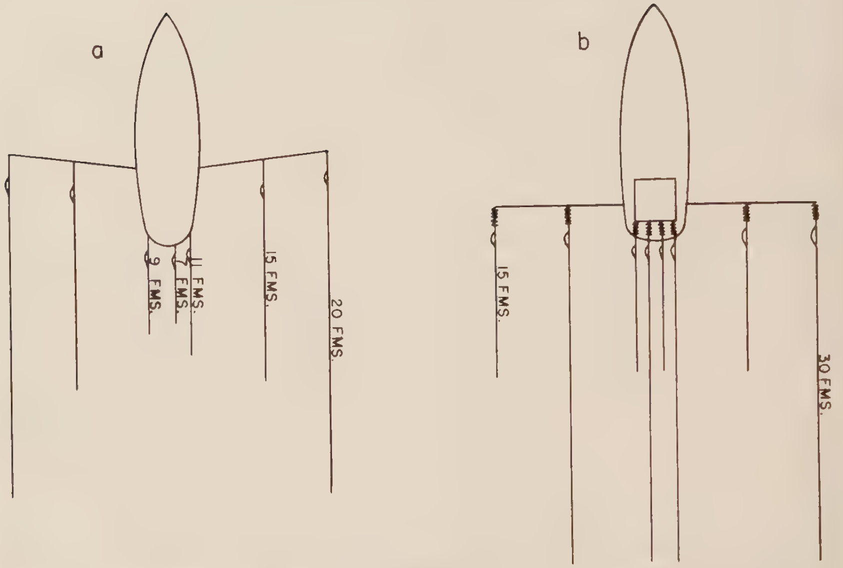


FIGURE 2. Arrangement and length of trolling lines on the *N. B. Scofield* (a) and *Hugh M. Smith* (b) albacore survey, 1959.

Longlines

Longlines used by the *Hugh M. Smith* were a modification of the gear originally developed at the Honolulu Biological Laboratory (Mann, 1955). Twenty baskets (210 fathoms per basket) of gear were fished at each longline station. The 12 droppers of a single basket were of varied length and in a set were arranged in three identical series as follows: 8, 2, 16, and 4 fathoms (Figure 3). Each dropper was buoyed separately to allow for a reasonably accurate estimate of the depth of capture.

Longlines were fished during daylight, usually from 0800 to 1400 hours. The gear required about 30 to 40 minutes to set and from 60 to 90 minutes to haul.

RESULTS OF FISHING

Trolling Catch

Of the three types of gear, trolling produced the only albacore catches. In all, 314 albacore were caught on trolling gear and of these, 207 were tagged and released (Table 1).

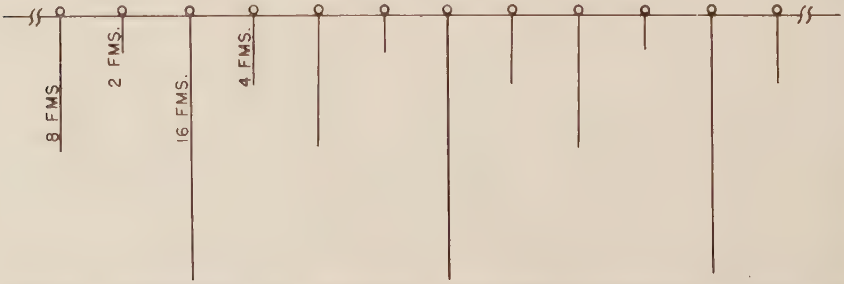


FIGURE 3. Arrangement of the droppers in a single basket (210 fathoms) of longline gear used on the *Hugh M. Smith* albacore survey, 1959.

TABLE 1

Troll Catches for the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of catch	Position		Species	Number caught	Number tagged	Surface temperature degrees F.
	N. lat.	W. long.				
N. B. SCOFIELD						
6/ 5/59	34°46′	122°25′	Albacore	1	0	59.0
	34°47′	122°28′	Albacore	10	6	59.0
	34°49′	122°33′	Albacore	2	1	59.0
	34°52′	122°38′	Albacore	3	2	59.0
	34°56′	122°49′	Albacore	10	9	59.4
	34°59′	122°54′	Albacore	11	6	59.0
	35°01′	122°57′	Albacore	3	1	59.0
6/ 6/59	35°42′	124°45′	Albacore	1	1	59.4
6/ 7/59	35°50′	125°59′	Albacore	2	1	60.1
	34°50′	126°06′	Albacore	8	5	61.0
6/ 8/59	34°39′	126°16′	Albacore	5	5	61.0
	34°20′	126°22′	Albacore	1	0	60.3
	34°15′	126°23′	Albacore	7	3	60.6
	34°10′	126°26′	Albacore	2	1	60.6
6/12/59	36°31′	128°23′	Albacore	1	0	60.8
	36°39′	128°22′	Albacore	3	3	60.8
	36°45′	128°19′	Albacore	1	0	60.8
6/13/59	37°07′	128°18′	Albacore	1	0	61.0
	37°30′	128°06′	Albacore	3	2	61.0
	36°56′	127°38′	Albacore	2	1	60.4
6/15/59	35°24′	126°32′	Albacore	1	0	60.8
	34°48′	126°04′	Albacore	2	1	61.2
	34°34′	125°51′	Albacore	13	8	61.3
	34°25′	125°43′	Albacore	3	1	61.5
6/16/59	33°54′	125°12′	Albacore	1	1	60.4
	33°40′	125°00′	Albacore	37	22	61.2
	33°38′	124°58′	Albacore	4	3	60.6
	33°17′	124°40′	Albacore	5	3	60.6
6/17/59	32°34′	123°58′	Albacore	1	1	61.7
6/18/59	33°08′	124°06′	Albacore	2	2	59.5
	33°11′	124°07′	Albacore	3	3	59.5
	33°13′	124°09′	Albacore	5	3	59.5
	33°18′	124°09′	Albacore	7	5	59.4
	33°19′	124°09′	Albacore	8	7	59.5
	33°21′	124°10′	Albacore	6	3	59.5
	33°26′	124°11′	Albacore	2	1	59.7
	33°31′	124°14′	Albacore	3	1	59.7
	33°33′	124°14′	Albacore	2	0	59.7
	33°35′	124°15′	Albacore	1	1	59.7
	33°38′	124°15′	Albacore	5	3	60.3
	33°39′	124°17′	Albacore	6	3	60.3
	33°46′	124°18′	Albacore	24	18	60.4
	33°51′	124°20′	Albacore	3	1	60.3
6/19/59	33°37′	124°30′	Albacore	1	1	60.4
	33°49′	124°28′	Albacore	5	2	60.4
	34°02′	124°24′	Albacore	3	2	60.1
	34°28′	124°29′	Albacore	2	2	60.8
6/19/59	34°43′	124°33′	Albacore	5	4	60.3
6/20/59	34°47′	124°34′	Albacore	1	1	60.4
	34°53′	124°36′	Albacore	1	1	59.7

TABLE 1—Continued

Troll Catches for the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of catch	Position		Species	Number caught	Number tagged	Surface temperature degrees F.
	N. lat.	W. long.				
	34°57′	124°37′	Albacore	4	3	61.0
	35°00′	124°38′	Albacore	4	4	60.8
	35°02′	124°38′	Albacore	1	1	60.8
6/21/59	35°20′	123°51′	Albacore	1	0	60.1
6/22/59	33°38′	123°04′	Albacore	1	1	59.9
	33°32′	123°02′	Albacore	1	1	60.6
	33°29′	123°01′	Albacore	10	6	60.4
	33°25′	123°00′	Albacore	8	5	59.9
	33°23′	122°59′	Albacore	3	1	58.6
	33°17′	122°57′	Albacore	2	2	58.8
6/23/59	32°20′	122°44′	Albacore	5	3	61.3
	32°25′	122°43′	Albacore	6	5	61.3
	32°26′	122°40′	Albacore	4	4	61.3
	33°05′	122°32′	Albacore	2	0	61.2
	33°12′	122°31′	Albacore	2	1	60.8
	33°15′	122°30′	Albacore	4	4	60.6
	33°25′	122°28′	Albacore	3	2	61.0
6/24/59	32°45′	121°30′	Albacore	2	2	61.0
	32°41′	121°28′	Albacore	2	2	61.2
	32°37′	121°26′	Albacore	5	5	61.2
	32°33′	121°22′	Albacore	3	2	61.0
H. M. SMITH						
4/29/59	23°29′	155°07′	Dolphin	1	0	73.0
5/ 3/59	33°09′	143°00′	Skipjack	2	2	63.9
5/ 9/59	36°44′	132°26′	Albacore	2	2	60.8
6/13/59	27°26′	121°49′	Skipjack	1	0	64.8

The *Hugh M. Smith* traveled approximately 6,000 miles during the 53 days of the cruise. This mileage was divided almost equally between the survey area, east of long. 125° W., and the preliminary route from Honolulu to this area. Lines were trolled for approximately 1,900 miles in the primary survey area and over 1,500 miles enroute, and 13 gill net and nine longline sets were made (Figure 4). Two albacore were caught on trolling lines and tagged some 500 miles west of San Francisco. Three skipjack *(Katsuwonus pelamis)* and a single dolphin *(Coryphaena hippurus)* were the only other fish caught on this gear.

The *N. B. Scofield* traveled approximately 2,400 miles during the 25-day cruise. Lines were trolled for about two-thirds of this distance and in addition a single gill net set was made (Figure 5). The first schools of albacore were encountered between 90 and 120 miles west by north of Point Arguello early in the cruise. Subsequently, 312 were caught of which 205 were tagged and released at numerous localities. Severe northwesterly weather conditions prevailing throughout the northern survey area hampered fishing in most areas. No other species of fish was caught by the *N. B. Scofield* on trolling lines.

Gill Net Catch

Of 13 gill net stations occupied by the *Hugh M. Smith*, all but three were in the primary survey area. The first set was made on May 4, and the last on June 18. All were made in water ranging from 57.5 to 65.8 degrees F. at the surface. No albacore were netted. Six other kinds of fish were caught, including: skipjack, Pacific bonito *(Sarda chiliensis)*, pomfrets, blue shark *(Prionace glauca)* and bonito shark *(Isurus glaucus)* (Table 2). A set was made on May 9, near where two albacore

TABLE 2
Gill Net Sets Made by the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of set	Position		Species	Number caught	Surface temperature degrees F.
	N. lat.	W. long.			
N. B. SCOFIELD					
6/11/59	35°35′	128°28′	No catch		61.2
HUGH M. SMITH					
5/ 4/59	34°48′	140°41′	Bonito shark	1	62.1
			Pomfret	25	
5/ 7/59	38°48′	135°06′	Blue shark	4	57.5
			Pomfret	7	
5/ 9/59	36°39′	132°24′	Blue shark	1	61.2
			Pomfret	2	
5/22/59	26°59′	121°59′	Skipjack	6	65.0
5/23/59	27°00′	120°56′	No catch		65.8
5/24/59	27°00′	119°31′	No catch		65.5
5/30/59	32°30′	118°20′	Blue shark	4	62.1
			Bonito shark	1	
5/31/59	32°08′	119°35′	Blue shark	3	60.0
6/ 4/59	30°28′	123°35′	No catch		62.2
6/ 9/59	28°50′	117°57′	Dolphin	1	64.5
6/10/59	29°23′	117°00′	Bonito shark	1	63.5
6/13/59	27°33′	122°15′	Pomfret	1	64.8
6/18/59	31°59′	117°46′	Pacific bonito	4	65.4
			Blue shark	4	
			Bonito shark	1	

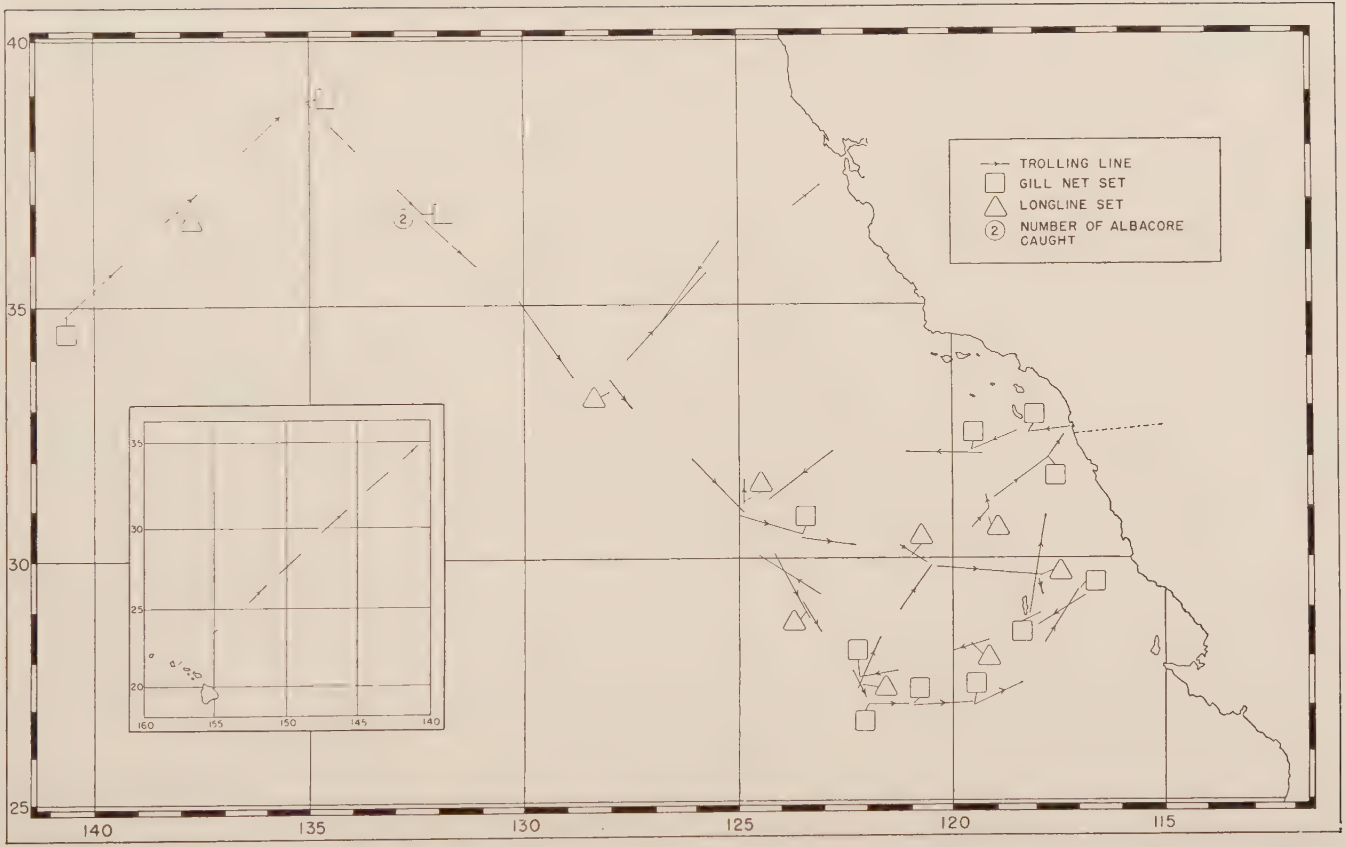

TROLLING LINE
GILL NET SET
LONGLINE SET
② NUMBER OF ALBACORE CAUGHT
②
40
35
30
25
140
135
130
125
120
115
35
30
25
20
160
155
150
145
140

FIGURE 4. Actual trolling lines of the *Hugh M. Smith* showing relative position of gill net and longline sets and the location of albacore catches. Inset shows trolling lines between Honolulu and long. 140° W.

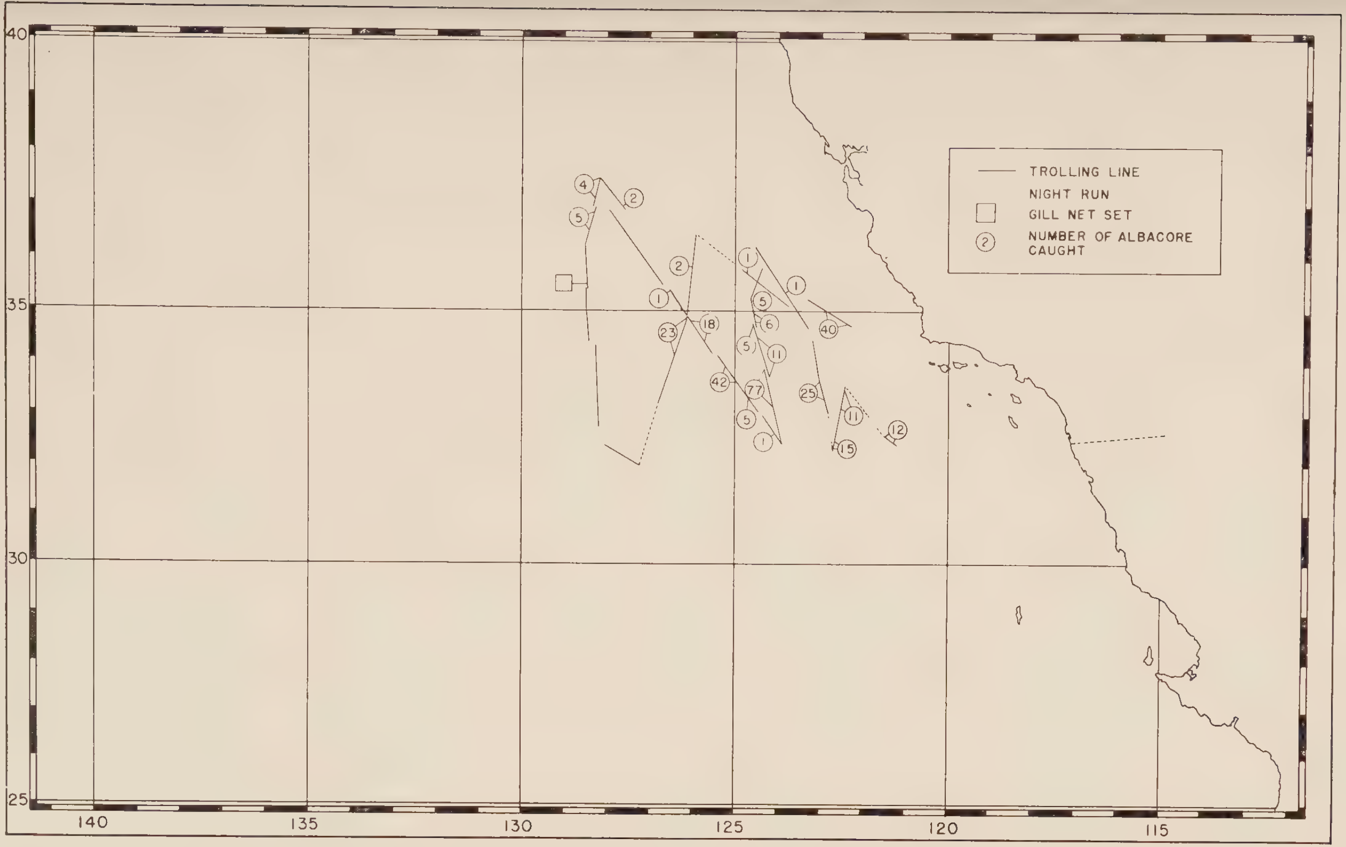

TROLLING LINE
NIGHT RUN
GILL NET SET
NUMBER OF ALBACORE CAUGHT
2
40
35
30
25
140
135
130
125
120
115
4
2
5
2
1
1
1
5
6
40
23
18
5
11
42
77
25
11
12
5
1
15

FIGURE 5. Actual trolling lines of the *N. B. Scofield* showing location of albacore catches and the relative position of the single gill net set.

had been caught on trolling lines, but only blue sharks and pomfrets were caught.

A single gill net set from the *N. B. Scofield,* approximately 390 miles west by north of Point Arguello on June 11, in 61.2-degree F. water, caught no fish.

Longline Catch

The first of nine longline stations occupied by the *Hugh M. Smith* was on May 6, and the last on June 17. All but two were in the primary survey area. Surface temperatures at the longline stations ranged from 60.9 to 64.7 degrees F. No albacore were caught, but three other kinds of fish including: bigeye tuna *(Parathunnus sibi),* hammerhead sharks (*Sphyrna* sp.) and blue sharks were taken (Table 3). The *N. B. Scofield* did not use this gear.

TABLE 3
Longline Sets Made by the HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of set	Position		Species	Number caught	Surface temperature degrees F.
	N. lat.	W. long.			
5/ 6/59	36°48′	138°05′	Blue shark	4	61.3
5/17/59	33°19′	128°01′	Blue shark	2	60.9
5/21/59	28°56′	123°27′	No catch		63.8
5/22/59	27°23′	122°09′	No catch		64.7
6/ 3/59	31°07′	124°56′	Blue shark	1	61.7
6/ 6/59	30°03′	120°58′	Blue shark	3	61.9
6/ 8/59	29°38′	117°55′	Bigeye tuna	2	63.6
			Blue shark	6	
			Hammerhead shark	1	
6/12/59	28°15′	119°34′	Blue shark	1	64.1
6/17/59	30°47′	119°10′	Blue shark	4	62.5
			Hammerhead shark	1	

SIZE RANGE OF THE ALBACORE CATCH

Based upon a frequency distribution of 199 albacore tagged by the *N. B. Scofield* (Table 4), over 80 percent of the catch was within the size range 630 to 680 mm. fork length (approximately 11 to 14 pounds). Lengths of untagged fish were similar and none was outside of the above size range. Weights recorded for the two albacore tagged from the *Hugh M. Smith* were 8 and 12 pounds, well within the overall size distribution.

SEA SURFACE TEMPERATURES AND ALBACORE OCCURRENCES

Rather comprehensive records of sea surface temperature were maintained aboard both vessels. In general, surface temperatures within 50 miles of shore varied from 54 degrees F. around Santa Rosa and San Miguel Islands to over 70 degrees F. along the immediate southern California coast and within a few hundred miles of the Hawaiian Islands. Offshore in the actual survey areas the range was between 57 and 65 degrees F.

Surface temperature records were sufficiently detailed to make it possible to construct rough isotherms within the survey area. Plotting

TABLE 4

Lengths of 199 Albacore Tagged from the N. B. SCOFIELD, Albacore Survey, 1959

Length (cm.)	Frequency	Percent	Length (cm.)	Frequency	Percent
56	1	0.5	67	25	12.6
57	0	--	68	15	7.5
58	1	0.5	69	8	4.0
59	2	1.0	70	0	--
60	1	0.5	71	0	--
61	2	1.0	72	1	0.5
62	7	3.5	73	1	0.5
63	15	7.6	74	1	0.5
64	36	18.1	75	0	--
65	48	24.1	--	--	--
66	34	17.1	81	1	0.5

albacore occurrences on a chart of these isotherms shows the relationship of the catches to surface temperature (Figure 6).

Ninety-eight percent of the albacore caught were from the rather restricted temperature range of 59.0 to 61.3 degrees F. (15.0 to 16.3 degrees C.). The remaining two percent were caught within plus or minus 0.4 degrees F. from these extremes (Table 5). Though surface temperatures where albacore occurred during May and June 1959 tended toward the lower extreme, they were predominantly within the range of 60 to 69 degrees F. from which California fishermen reported over 90 percent of their catch during the period 1955 through 1957.

TABLE 5

Albacore Troll Catches by Temperature, Albacore Survey, 1959

Temperature		Catch		Temperature		Catch	
Degrees C.	Degrees F.	Number	Percent	Degrees C.	Degrees F.	Number	Percent
14.8	58.6	3	0.96	15.8	60.4	44	14.01
14.9	58.8	2	0.64	15.9	60.6	23	7.32
15.0	59.0	30	9.55	16.0	60.8	17	5.41
15.1	59.2	0	0.00	16.1	61.0	29	9.23
15.2	59.4	18	5.73	16.2	61.2	48	15.29
15.3	59.5	24	7.64	16.3	61.3	28	8.92
15.4	59.7	9	2.87	16.4	61.5	3	0.96
15.5	59.9	9	2.87	16.5	61.7	1	0.32
15.6	60.1	6	1.91				
15.7	60.3	20	6.37				
				Total		314	100.00

SUMMARY

1. In an attempt to obtain an early opening for the 1959 season and to learn the route of the spring migration of albacore a joint, preseason survey of the fishing grounds was carried out by the California Department of Fish and Game and the Honolulu Biological Laboratory, U.S. Bureau of Commercial Fisheries.

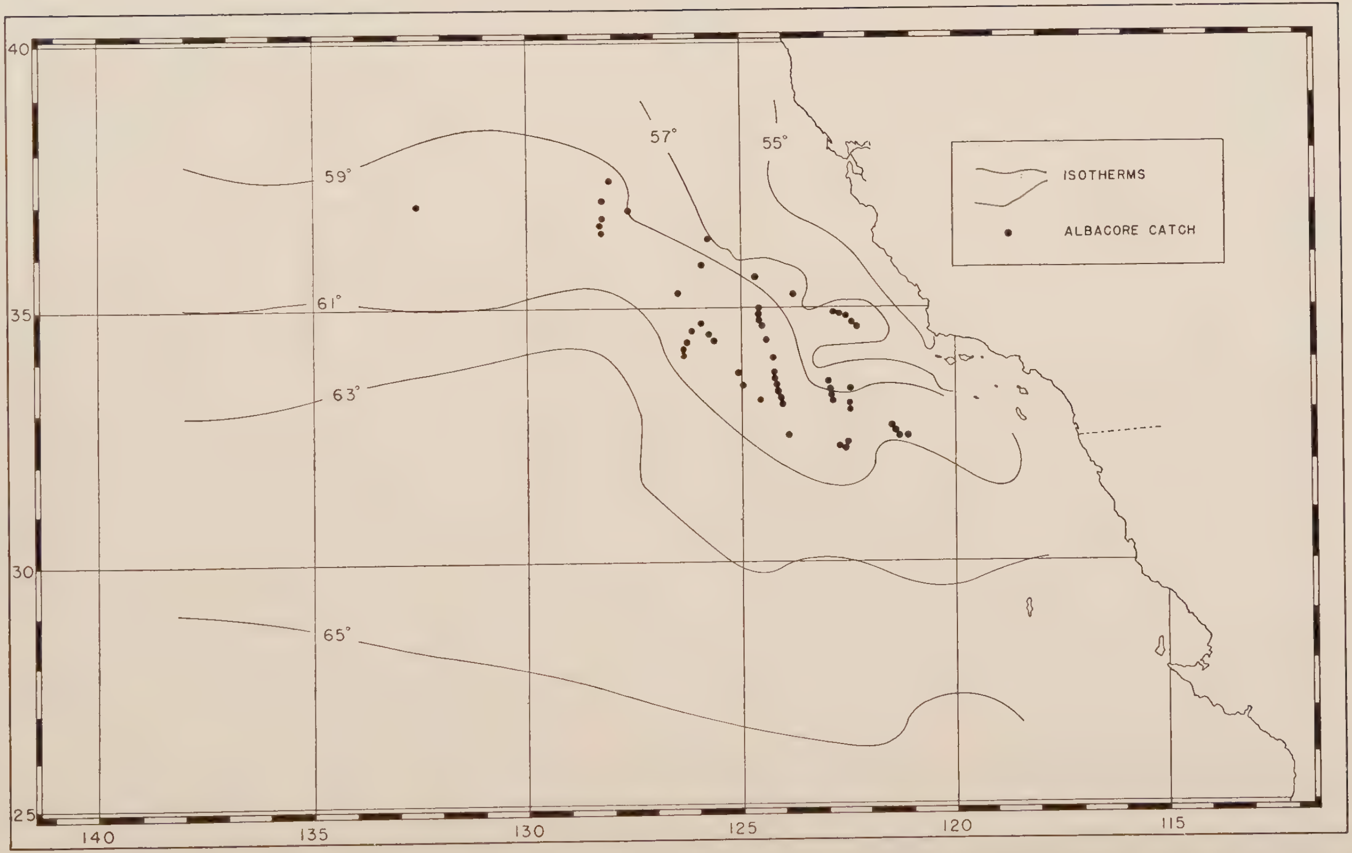

ISOTHERMS
ALBACORE CATCH
55°
57°
59°
61°
63°
65°
40
35
30
25
140
135
130
125
120
115

FIGURE 6. Albacore catch locations related to surface isotherms, by two degree F. intervals, as interpreted from sea surface temperature data collected during the 1959 survey.

2. The California Department of Fish and Game vessel *N. B. Scofield* surveyed the offshore fishing grounds north of Lat. 32° N. from June 1 through June 25, 1959. The Bureau of Commercial Fisheries vessel *Hugh M. Smith* surveyed to the south of Lat. 32° N. from April 28 through June 19, 1959.
3. Fishing gear consisted of feather and bone jigs, longlines and gill nets.
4. Trolling north of Lat. 32° N. produced the only catches of albacore. Of 314 caught trolling, 207 were tagged and released.
5. Fourteen gill net sets and nine longline sets caught no albacore. These two types of gear did produce small catches of bigeye tuna, skipjack, Pacific bonito, pomfrets, dolphin, blue shark, bonito shark and hammerhead shark.
6. The predominant size group of albacore caught was from approximately 11 to 14 pounds.
7. Offshore sea surface temperatures ranged from about 57 to 65 degrees F. Albacore occurrences were limited to a range between 58.6 and 61.7 degrees F.

ACKNOWLEDGMENTS

The authors wish to extend their gratitude to the captains and crews on the *N. B. Scofield* and the *Hugh M. Smith*. Without their splendid support, often under trying conditions, the data presented in this paper could not have been obtained.

LITERATURE CITED

Clemens, Harold B.
1955. Catch localities for the Pacific albacore *(Thunnus germo)* landed in California, 1951 through 1953. Calif. Dept. Fish and Game, Fish Bull. 100, 28 pp.

Clemens, Harold B.
n.d. Migration and growth of the Pacific albacore *(Thunnus germo)*. Calif. Dept. Fish and Game, Mar. Res. Oper. Manuscript.

Graham, Joseph J., and William L. Craig
n.d. Oceanographic observations made during a 1959 albacore *(Thunnus germo)* survey off the North American west coast. U. S. Bur. Comm. Fish., Honolulu Biol. Lab. Manuscript, 1960. (To be published in Spec. Sci. Rept.: Fish. Series.)

Graham, Joseph J., and Herbert J. Mann
1959. Construction and catch selectivity of albacore gill nets used in the central north Pacific. U. S. Fish and Wildl. Serv., Comm. Fish. Rev., vol. 21, no. 8, pp. 1-6.

Mann, Herbert J.
1955. Construction details of improved tuna longline gear used by P.O.F.I. U. S. Fish and Wildl. Serv., Comm. Fish. Rev., vol. 17, no. 12, pp. 1-10.

Scofield, W. L.
1956. Trolling gear in California. Calif. Dept. Fish and Game, Fish Bull. 103, 45 pp.

o

printed in CALIFORNIA STATE PRINTING OFFICE

33014 1-61 200

Mass Culture of Phytoplankton as Foods for Metazoans

Abstract. An apparatus for mass culture of photosynthetic microorganisms has been developed to grow algae for use as foods for larval and juvenile mollusks in studies of their physiological requirements. The apparatus consists of a series of 5-gal growth chambers, and the system can be enlarged to yield any desired volume of algae by replication of basic units. Approximately 50 lit. of algal suspension, averaging about 0.5 ml of packed wet cells per liter, are produced daily.

In developing a standard technique for rearing lamellibranch larvae, one of the requirements was to provide an adequate quantity of food. To be ingested by early-swimming larvae of the American oyster, *Grassostrea virginica*, food particles must be in suspension and must not be larger than about 7 μ in size.

Photosynthetic nannoplankton appeared to be the most promising natural food. It was found, however, that various species of microorganisms not only differ in food value, but that some are not utilized at all, while others are actually toxic (*1*, *2*). Some produce toxins that appear to be intracellular but, more commonly, toxins occur as external metabolites. Certain bacteria also produce toxins (*3*). In low concentrations these toxins only retard the growth of bivalve larvae, but sometimes concentrations are sufficient to prevent development of eggs, or kill larvae (*4*).

To provide food for the daily feeding of the larval and juvenile mollusks at this laboratory, from 20 to 60 lit./day of a relatively dense culture of food organisms in unialgal and, preferably, bacteria-free culture are needed. For a pilot or commercial hatchery for clams or oysters this requirement could easily be from 100 to 1000 gal daily. The objective, therefore, was to develop a culture apparatus that is inexpensive, simple to operate, and capable of producing any desired volume of the food culture. A number of comparatively small basic units is preferable to a single larger unit, since several species of algae can then be produced simultaneously. This is important because a mixture of several species of microorganisms often causes better growth of larvae than any single species (*2*), and because larvae of different bivalves require different foods. Moreover, the best foods for larvae are not necessarily the best foods for juveniles of the same species.

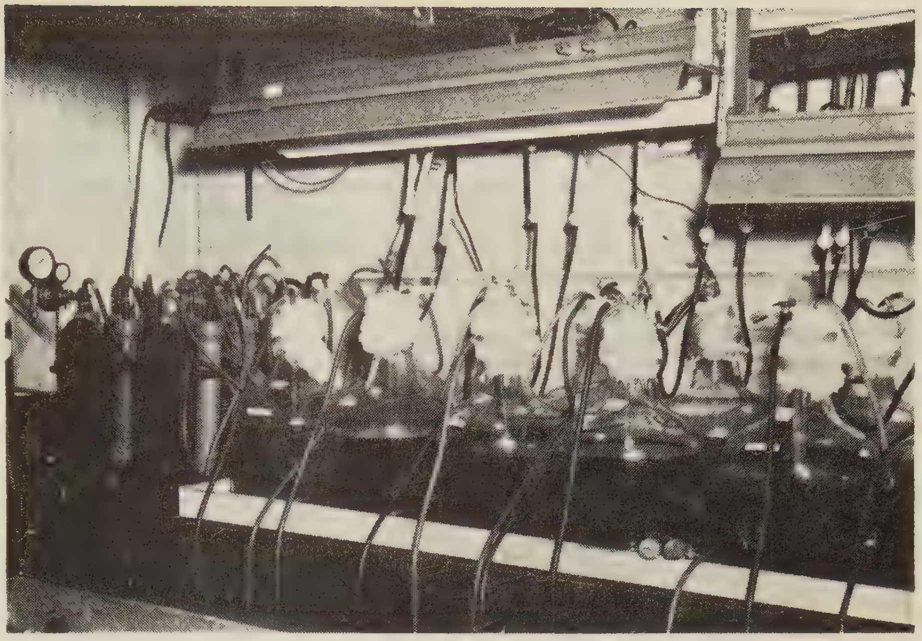


Fig. 1. Culture apparatus, showing carboy growth chambers in water bath and arrangement of lights.

Use of algae as food is not, of course, confined to bivalves and their larvae. There are filter-feeding representatives of almost every phylum of aquatic invertebrates that subsist on algae either during early stages of their development or throughout their lives. Development of a dependable method for growth and maintenance of mass cultures of algae is, therefore, a requirement for keeping large colonies of these aquatic animals healthy.

Our culture apparatus accommodates 16 5-gal Pyrex carboys or 20 9-lit. Pyrex serum bottles as growth chambers. Vigorous agitation, by bubbling a mixture of air and CO_2 through the cultures, keeps the contents of the chamber thoroughly mixed. This prevents stratification and helps to expose all cells to periods of intense illumination. The growth chambers are immersed to a depth of 3 or 4 inches in a water bath kept at 19° ± 1°C by a force-flow constant temperature unit. Lighting is provided by four 40-watt, cool-white fluorescent tubes situated behind the back row of growth chambers and three 40-watt tubes suspended above the front row (Fig. 1).

About 1.5 lit. of culture are withdrawn daily from each serum bottle growth chamber, or 3 lit./day from

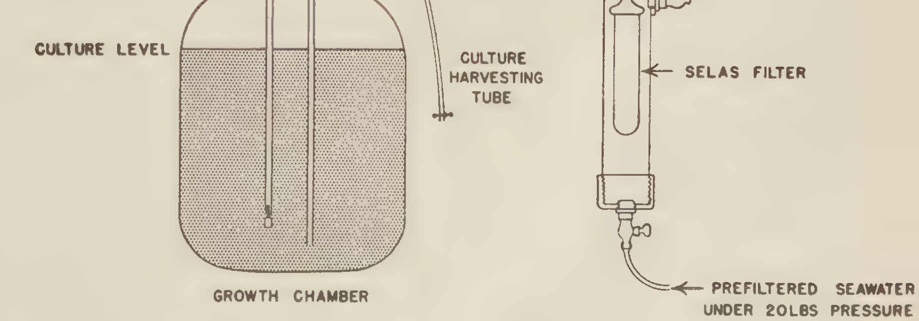


Fig. 2. Diagram of culture apparatus, which uses Selas filter for sterilizing sea water.

each carboy. Although the various species of algae differ in their rate of growth and final density maintained, some of our cultures have been maintained at this rate of productivity for more than a year, yielding about 0.75 ml of packed wet cells daily from each 9-lit. serum bottle, or 1.5 ml/day from each 5-gal carboy. A volume of sterile sea water and nutrient salts, equal to the volume of culture drawn off, is aseptically added to the growth chamber each day.

Mass cultures of chrysomonads, cryptomonads, chlorophytes, and diatoms have been grown successfully in our apparatus. They include *Isochrysis galbana, Monochrysis lutheri, Dicrateria inornata, Dicrateria* sp. (BII), *Chromulina pleiades, Phaeodactylum tricornutum, Cryptomonas* sp., *Dunaliella euchlora, Dunaliella primolecta, Chlorella* sp. (580), and *Skeletonema costatum.*

Much of the labor involved in older methods that use heat sterilization has been eliminated by using a "cold" method of sterilization of the media added to the growth chambers. A number of "cold" methods of sterilization were tested but, until lately, none had proved satisfactory. Recently, by placing a ceramic filter (Selas No. FP-128-03) in the intake line for each growth chamber (Fig. 2), a satisfactory system has been developed. The sea water is first passed through "Fulflo" Orlon filters to remove larger particles, nutrient salts are added, and this solution is forced through the ceramic filter (maximum pore size 0.6 μ) to replace the culture drawn off.

The growth chamber and Selas filter, together with the tubing connecting them, can be autoclaved already assembled. The casing, into which the Selas filter fits, is of polyvinyl chloride, and the stopcocks are of hard rubber and are not autoclaved. The cap at the upper end of the case is slotted so that it can be fitted over the tubing and stopper after the sterile Selas filter is inserted. This permits periodic disassembly and washing of the outside of the filter in hot water without disturbing the sterile system.

Occasionally growth of algae in enriched sea water is poor, either because of the absence of some essential nutrient normally present in sea water or because of the presence of some toxin. Some artificial sea waters, such as that used by Provasoli *et al.* (*5*), are satisfactory and give uniform results, but their use would be expensive and their preparation time-consuming if used for large-volume cultures. When the nutrient requirements of each of the species of algae under cultivation are known, it should be possible to add a complete nutrient mixture to sea water so that algal cultures will grow well at all times, except during those probably rare periods when toxic elements or metabolites are present in high enough concentrations to retard growth.

HARRY C. DAVIS
RAVENNA UKELES
U.S. Bureau of Commercial Fisheries, Biological Laboratory, Milford, Connecticut

References

1. H. C. Davis, *Biol. Bull.* **104**, 334 (1953).
2. ——— and R. R. Guillard, *U.S. Fish Wildlife Serv. Fishery Bull. No. 136*, 58, 293 (1958).
3. R. R. Guillard, *Proc. Natl. Shellfish Assoc.* **48**, 134 (1958); *Biol. Bull.* **117**, 258 (1959).
4. H. C. Davis and P. E. Chanley, *Proc. Natl. Shellfish. Assoc.* **46**, 59 (1955).
5. L. Provasoli, J. J. A. McLaughlin, M. R. Droop, *Arch. Mikrobiol.* **25**, 392 (1957).

14 March 1961

DiCostanzo and Hayes. Science in Alaska
1960. Proceedings Eleventh Alaska
Science Conference.

28

high survival of fry (22.4 percent); a large absolute number of seaward migrating fry (585,000); and a high marine survival (6.1 percent). This large spawning run provided an opportunity for comparison of spawning characteristics with small runs of previous years.

The major obvious difference between the large and small runs was the distribution of spawning fish. In most recent years, when runs have been small, spawning has been concentrated in the lower part of Sashin Creek. This lower stream is characterized by moderate gradient, fine gravel (averaging walnut size), and uniform depth. The general appearance of this lower section is what biologists would judge to be ideal for salmon production. The upper stream, in contrast, has a steep gradient, coarse gravel with many large rocks and boulders, and water depths ranging from periodically exposed bars to deep pools.

This difference in distribution of spawners was in itself not remarkable and might be expected because of population pressures. An additional significant fact came to light in the spring of 1960 incidental to another project. To estimate total fry production from the stream, a series of 303 square-yard areas, distributed randomly throughout the stream, were excavated by pumping a water-air mixture into the gravel. It was noted that the greatest density of live fry was in the upper steep section where there had been fewer spawners. Thus, this area was far more productive than the lower-gradient section near the mouth of the stream.

The actual causes of this survival differential are unknown, but it is certain that gradient, if not a factor *per se*, is at least associated with survival at Little Port Walter.

Discussion

The biological implications of early versus late spawning and of high gradient versus low gradient production with large and small runs are most significant:

Pink salmon invariably mature at two years of age, so alternate years' runs comprise separate races even in the same stream. For unknown reasons, it is characteristic of pink salmon runs to be alternately large and small in adjacent years. At Sashin Creek in recent years the odd-year runs have been larger than even-year runs, and odd-year runs have spawned earlier and have had higher survival than even-year runs. This has made the odd-year runs inherently more productive than even-year runs, and has tended to preserve alternating years of large and small runs.

Furthermore, small runs choose the less productive low-gradient stream area for spawning, and portions of large runs utilize the more productive high-gradient stream areas. This tends to maintain the numerical differential between alternate large and small runs, augmenting the large runs and depressing the small ones.

It would be premature at this time to extrapolate the data from Little Port Walter to other streams, as it is not known whether the same phenomena occur in other areas. A great deal of further study over a wide geographical range is needed to determine whether they are generally applicable.

A METHOD OF SEPARATING RIVER STOCKS OF RED SALMON IN THE BRISTOL BAY FISHERY

Charles J. DiCostanzo and Murray L. Hayes
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries, Auke Bay, Alaska

The fishery for red salmon (Oncorhynchus nerka) in Bristol Bay is confined by regulation to the immediate vicinity of the mouths of the Bay's five major river systems. This restriction results in five fishing districts, each of which is separated from others by 30 to 40 miles of coastal waters which are closed to fishing.

Red salmon stocks destined for the different spawning systems intermingle while passing through the several fishing areas.

A method of separating the commercial catch of each district into its component stocks is presented in this report. In the simplest case the method is based upon the assumption that the proportional frequencies of a particular character (age group frequency distributions used as an example) in the commercial catch is dependent only upon the rates of intermingling of several stocks within the fishing areas.

Under this special condition the number of individuals falling into a particular class in the commercial catch in a district may be expressed as follows:

$$\sum_{j=1}^{J} P_{ij}N_j = P_{ig}N$$

where P_{ij} = the proportional frequency of individuals of the i^{th} class in the j^{th} stock.

N_j = the number of individuals of the j^{th} stock taken in the commercial fishery.

P_{ig} = the proportional frequency of individuals of the i^{th} class in the commercial catch.

N = the number of individuals in the commercial catch.

P_{ij} and P_{ig} are determined by sampling and N is determined from catch data. If the number of classes is equal to or greater than the number of stocks contributing to the commercial catch, a simple algebraic solution for the N_j's is available by the method of simultaneous equations.

The use of characters having continuous frequency distributions is discussed as well as the use of the method generally in population studies. Limitations of the method and problems in its application are also discussed.

APPLICATIONS OF THE PARKER EQUATION TO GROWTH OF AQUATIC ORGANISMS

P. A. Larkin and K. V. Ayyangar, Institute of Fisheries
University of British Columbia, Vancouver

Parker and Larkin (1959) suggested the use of the differential equation $\frac{dw}{dt} = kw^x$ in the description of growth of chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Salmo gairdnerii). Essentially the use of this equation implies that growth can be treated like any other physiological function. For instance, respiration rate is commonly related to weight by the equations:

$$\frac{\Delta O}{\Delta t} = kw^x$$

where O represents oxygen uptake

w represents weight.

The respiration rate equation is usually expressed algebraically as:

$$\log \left(\frac{\Delta O}{\Delta t}\right) = \log k + x \log w$$

Treating the growth equation in the same way would yield:

$$\log \left(\frac{\Delta w}{\Delta t}\right) = \log k + x \log w \qquad (1)$$

The question arises as to whether growth rate is related to initial weight, average weight, or final weight during the period t. The solution to this kind of problem is to deal in instantaneous rates, integrating the expression

$$\frac{dw}{dt} = kw^x$$

to yield:

$$w_t^{(1-x)} = (1-x)\,kt + w_o^{(1-x)} \qquad (2)$$

Using the expression $w = q\ell^y$ to denote the relationship between weight and length it can be demonstrated that growth in length can be depicted as:

$$\ell^z_{t+1} = \alpha + \ell^z_t \qquad (3)$$

where $z = y(1-x)$

$$\alpha = \frac{k(1-x)}{q^{(1-x)}}$$

Setting $\ell^z_{t+1} = \alpha$

and $\ell^z_{t=n} = n\alpha$

Taking logarithms and dividing by $\frac{1}{z}$:

$$\log \ell_n = \frac{1}{z} \log \alpha + \frac{1}{z} \log n \qquad (4)$$

Plotting $\log \ell$ against log t (i.e. log n) yields a straight line with slope $\frac{1}{z}$. The solution is made difficult

29

JOURNAL OF GEOPHYSICAL RESEARCH VOLUME 66, NO. 3 MARCH 1961

Effects of Wind-Induced Advection on Sea Surface Temperature

L. E. EBER

U. S. Bureau of Commercial Fisheries
Biological Laboratory, Stanford, California

Abstract. Wind-induced advection is one of the mechanisms through which conditions in the surface layer of the ocean can be affected by atmospheric fluctuations. An attempt was made to assess the relative importance of this mechanism in the northeast portion of the Pacific Ocean for two periods, fall 1957 and winter 1957–1958. Sea conditions were represented by sea surface temperatures averaged over the middle 10 days of each month and by anomalies of these 10-day means from long-term monthly normals. Anomalous sea temperature advection was determined by using surface water displacements computed solely from monthly mean geostrophic wind anomalies. Observed sea temperature anomaly changes within each of the two seasons were then compared with the computed advective sea temperature anomalies. Good agreement was found for the winter period and poor agreement for the fall period. The results for the winter period (but not for the fall period) showed a stronger correlation between computed advective and observed sea temperature anomalies than was found earlier by Namias for the same two cases. The principal modification to Namias's procedure which was made in the present study involved an attempt to take into account the initial state. It was concluded that advection may have had a dominant effect on sea surface temperature in the winter case, but was subordinate to other processes during the fall case.

Introduction. Large-scale anomalies of substantial magnitude are known to occur in monthly and seasonal mean distributions of sea surface temperature. Empirical evidence has pointed to the existence of an interrelationship between such anomalies and the surface wind, but the relative importance of various wind-connected mechanisms, such as advection or upwelling, has not been conclusively established.

Namias [1959] attempted to clarify the role of advection in the production of sea temperature anomalies by comparing observed anomalies in the northeast Pacific with independent estimates of wind-induced advective anomalies. His procedure is described in the paper cited. Briefly, it entails the computation of wind-induced displacements of surface water from seasonal pressure anomaly charts, using the geostrophic relation to determine wind from pressure, and Ekman's empirical formula relating wind speed to surface water current, expressed as follows:

$$v/w = 0.0127/\sqrt{\sin \phi}$$

where v is the speed of the surface water current, w is the wind speed, and ϕ is latitude. The direction of the surface wind drift was assumed to be 45° to the right of the wind.

By superimposing the displacement vectors onto the normal sea surface isotherms appropriate to the season, Namias obtained a computed seasonal temperature anomaly due to the advection of surface water by the anomalous wind.

Observed seasonal sea temperature anomalies were obtained from 10-day mean anomaly charts prepared by Bureau of Commercial Fisheries Biological Laboratory, Honolulu. The 10-day anomalies represent the deviations of temperatures, averaged over the middle 10 days of each month, from monthly normals published by the *U. S. Hydrographic Office* [1944].

Comparing the corresponding fields of observed and computed anomalies for several seasons during 1957, Namias found a small measure of agreement in the broad-scale patterns. Considering this outcome in view of the assumptions made in computing the advective changes, and the neglect of nonadvective processes, he concluded that effects other than simple surface

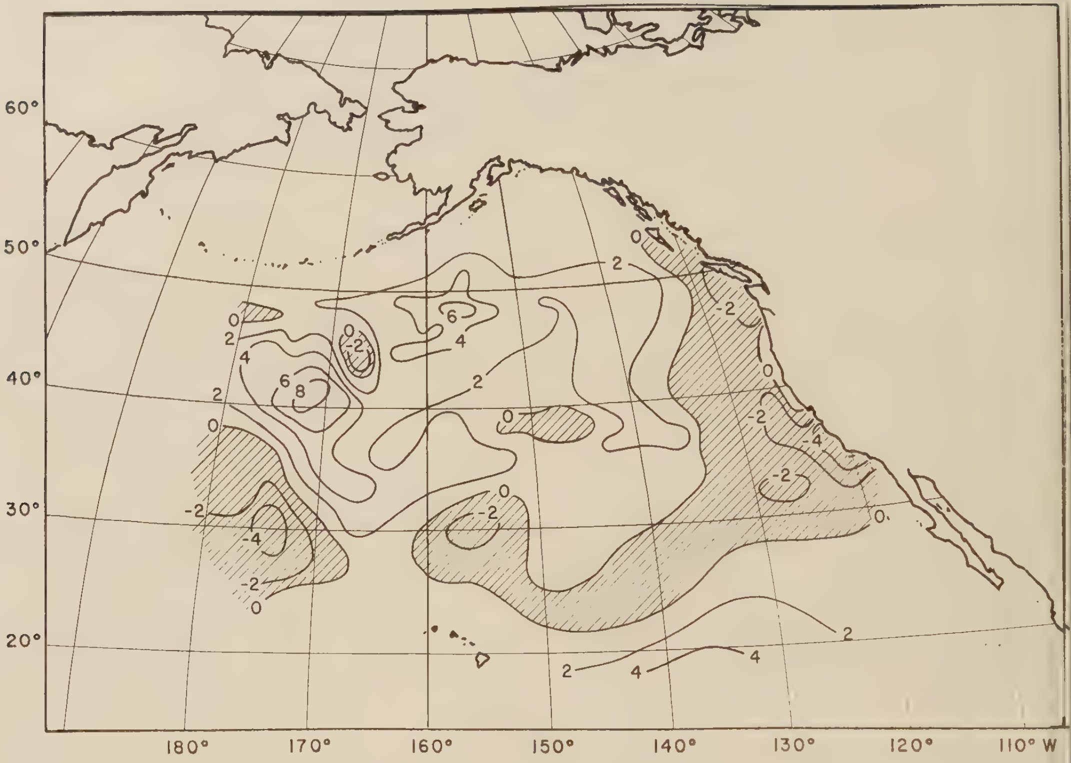


Fig. 1. Observed change of sea surface temperature anomalies (°F) between September 11–20, 1957, and November 11–20, 1957.

advection must contribute significantly to the observed anomalies.[1]

The strength of this conclusion, however, is weakened by the acknowledged fact that the computations were subject to stringent assumptions. If advection in the real ocean has a more dominant influence on sea temperatures than is indicated by Namias's results, the removal of one or more of these assumptions should reveal a closer agreement between computed and observed patterns.

Implicit in Namias's procedure is the assumption that the ocean current velocities were initially normal, and that the only deviations from normal occurring during the period of computations were those induced by the anomalous winds. As Namias noted, little can be done toward removing this assumption until our knowledge of the ocean currents is greatly augmented.

A further limitation inherent in his procedure also pointed out by him, is the assumption that sea temperatures were normal in the initial state. Since this condition is frequently not satisfied in the real ocean, a more realistic approach would be to determine the *change* in the anomaly of sea surface temperature, between the beginning and end of a period, for comparison with the computed effects of advection by anomalous winds.

Two of the seasons investigated by Namias (fall 1957 and winter 1957–1958) were characterized by substantial temperature anomalies at their onset, that is, in September 1957 and December 1957, respectively. In consequence o

---

[1] In a personal communication to the author, Namias has indicated that his latest studies suggest better agreement than he had expected between observed sea surface temperature anomalies and those computed by the above method when the period of averaging is a month rather than a season. Furthermore, he considers the sea surface temperature charts, currently prepared by the Bureau of Commercial Fisheries, which represent averages for full months rather than only for the central 10 days to be an obvious improvement for studies of this kind.

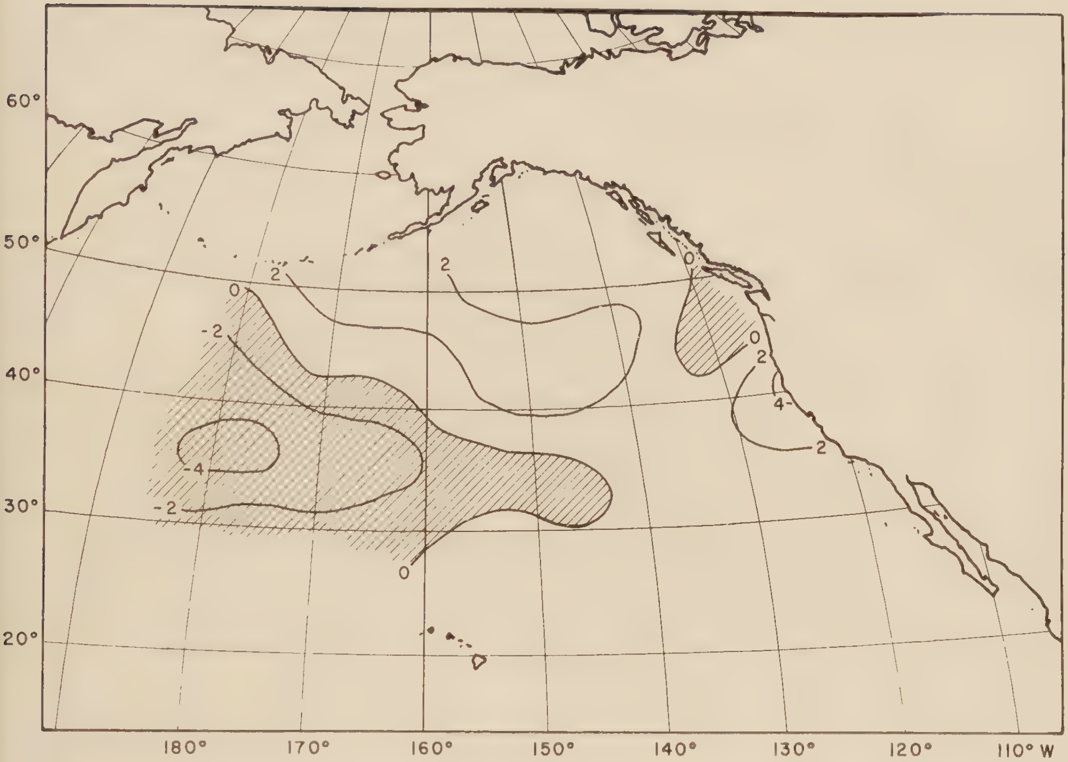


Fig. 2. Advective anomalies of sea surface temperature computed for the period September–October, 1957.

the considerations mentioned above, it appeared worth while to examine the within-season changes of the observed anomalies for these two cases to see whether they would reveal a closer correspondence with computed advective changes than did the average seasonal anomalies.

Computation of observed and advective anomaly change. Observed anomaly changes were computed by graphical subtraction from the same source data that Namias used. For example, the difference between the anomaly charts for September 11–20 and October 11–20, 1957, was taken as the 1-month change from mid-September to mid-October. One-month anomaly changes were also computed for mid-October to mid-November, 1957; mid-December, 1957, to mid-January, 1958; and mid-January to mid-February, 1958.

Similarly, 2-month anomaly changes were obtained for mid-September to mid-November, 1957, representing the fall case, and for mid-December, 1957 to mid-February, 1958, representing the winter case.

Independent computations of anomalous wind-induced advective temperature changes were made by using a procedure analogous to that followed by Namias, that is, by determining surface water displacements from geostrophic wind data and Ekman's wind-water current relationship, and superimposing the results on isotherm charts to arrive at an estimate of temperature advection. The procedure differed from that of Namias in that the winds were derived from monthly, instead of seasonal, anomalies of sea level pressure and the isotherm charts used represented the particular months under investigation, rather than long-term normals.

Charts of computed advective anomaly change where prepared for the months of September, October, and December, 1957, and for January 1958. The charts for September and October, and similarly those for December and January, were combined to give charts of advective changes for 2-month periods.

Results. The monthly charts of anomaly

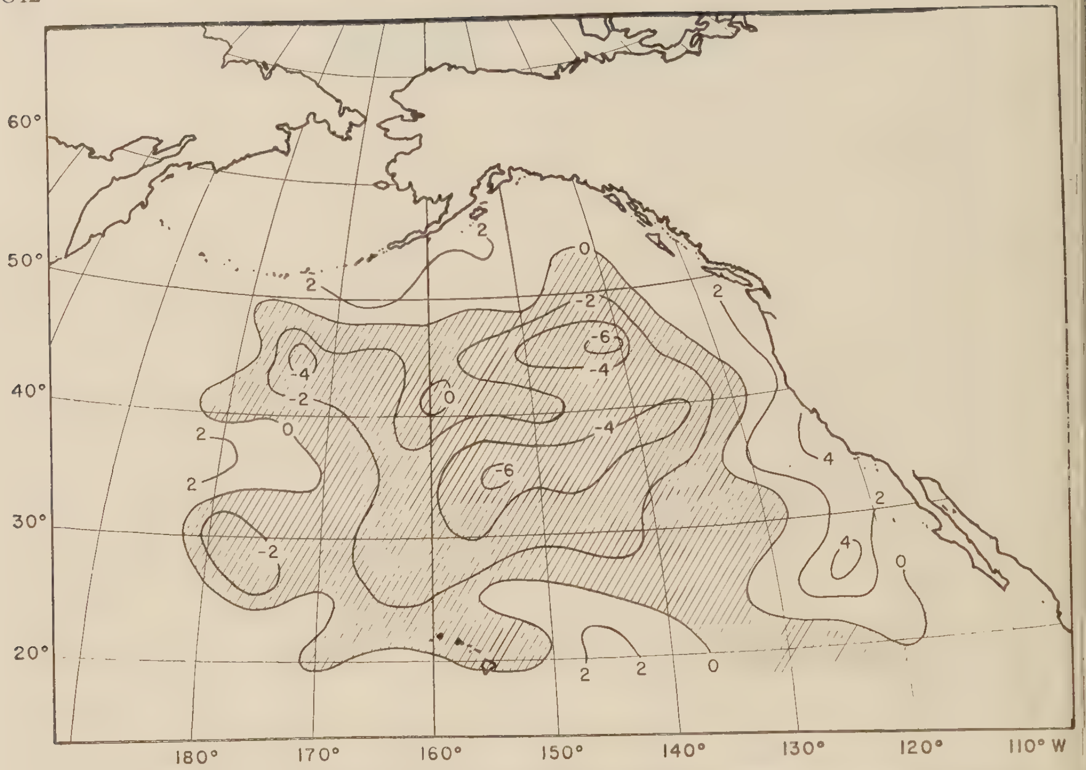


Fig. 3. Observed change of sea surface temperature anomalies between December 11–20, 1957, and February 11–20, 1958.

change are not reproduced and will be discussed only briefly. Since the observed charts represent approximately mid-month to mid-month intervals and since the advective charts represent calendar months, the respective periods of corresponding observed and advective changes overlap by 50 per cent at most. An examination of all such overlapping pairs without any consideration of lag, revealed little or no evidence of correlation. However, the month-to-month fluctuations in both sea temperature and pressure anomaly patterns were found to be large; hence the mismatching of periods may have obscured any relation between causal influences and effects.

The computed and observed anomaly changes for 2-month intervals are shown in Figures 1, 2, 3, and 4. Here a more critical comparison of computed and observed values can be made, since their respective periods have a 75 per cent overlap.

Examining first the charts for fall 1957, we see a more complex pattern in the observed anomaly changes for mid-September to mid-November (Fig. 1) than in the advective changes for September-October (Fig. 2). Both charts show generally positive anomaly changes in the Gulf of Alaska and in the adjacent region southward to about 40°N. However, the anomalous warming in excess of 4°F which appears in Figure 1 between 45°–50°N, 155°–160°W, does not occur in the chart for advective change, Figure 2. Along the west coast of North America there is fair agreement in the region of British Columbia and Washington, but contradictory values occur farther south. In both charts regions of anomalous cooling appear to the northwest of Hawaii, with minima below −4°F. The centers of these minima, however, are displaced from each other by nearly 500 miles. The greatest discrepancy occurs south of the Aleutians near 40°N, 170°W, where Figure 1 shows anomalous warming of more than 8°F while the advective chart indicates cooling. Thus

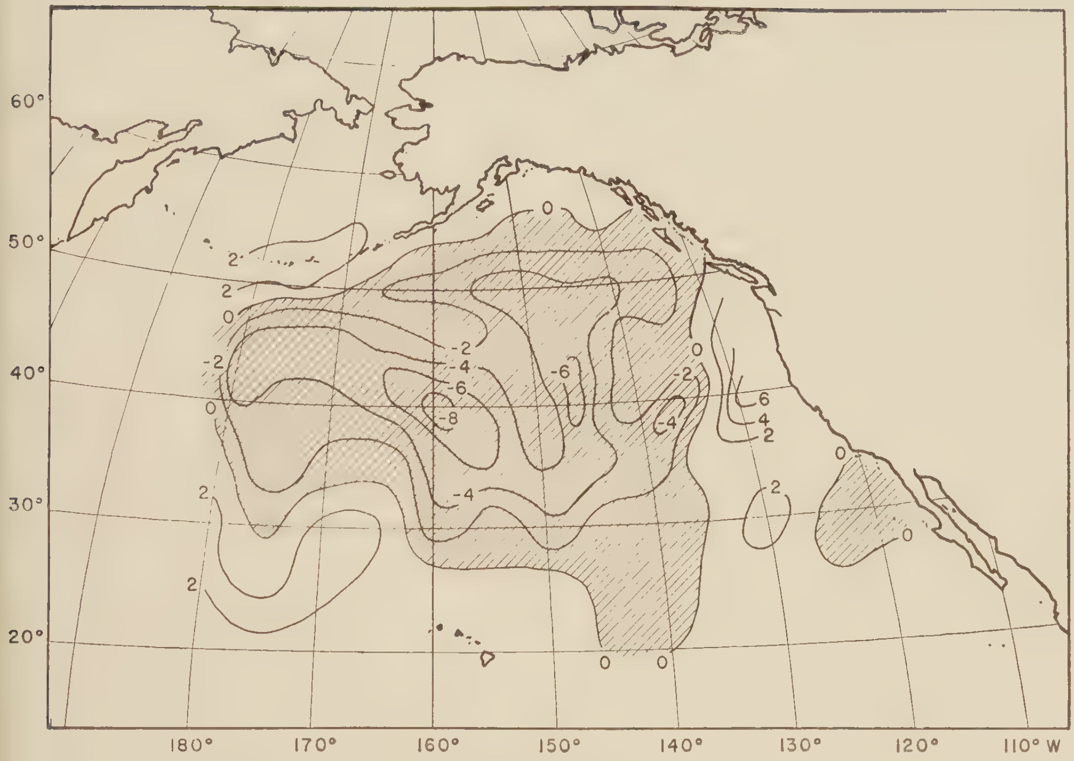


Fig. 4. Advective anomalies of sea surface temperature computed for the period December, 1957–January, 1958.

while suggestive similarities can be seen in the large-scale features of the two charts, the over-all agreement is rather poor.

Certainly, the argument for advection is not advanced in this case by substituting the within-season anomaly changes (Fig. 1) for the mean seasonal anomalies shown by Namias (Fig. 4 of his report). It should be mentioned that Namias's computed advective anomalies for fall 1957 (Fig. 14 of his report), although generally similar to Figure 2, indicate much greater cooling in the vicinity of 40°N, 170°W. Moreover, the distribution of negative advective anomalies shown on Namias's chart for this area appear to correspond to a similarly situated, although less intense, center of minimum values in his observed anomaly chart for the same season. However, the latter feature reflected a condition already present at the beginning of the season (Sept. 11–20) and might not be related to the average advection throughout the season.

The results for the winter of 1957–1958 are quite different. The observed temperature anomaly changes over the interval December 11–20, 1957, to February 11–20, 1958 (Fig. 3), show a striking similarity in general pattern and magnitude to the advective changes computed for December 1957 and January 1958 (Fig. 4). Both charts show anomalous cooling over most of the region from 25° to 50°N and 135° to 175°W. Positive changes also prevail over most of the surrounding areas in both cases. Discrepancies can be seen in the small-scale features on the two charts, but these do not detract from the over-all likenesses to the extent found in the fall of 1957.

Again, when the results are compared with Namias's work, it can be stated that the computed advective anomaly patterns agree substantially better with the observed within-season anomaly changes (Fig. 3) than with the observed mean anomalies for winter 1957–1958 shown in Figure 5 of his report. The advective anomalies shown in Figure 4 for this case also agree well with those computed by Namias for the winter season (Fig. 15 of his report).

Discussion. One might interpret these results as indicating that advection was a dominant factor during the winter but played a subordinate role to other influences during the fall. That such a hypothesis is at least tenable is suggested by a statistical study of monthly mean geostrophic wind components and sea surface temperatures observed at British Columbia shore stations. This work (to be published), based on a 19-year period, showed a significant correlation between wind and temperature anomalies in winter months but negligible correlation in late summer and early fall months.

One factor which may affect the relative effect on sea surface temperature of various mechanisms, at different times of the year, is the seasonal variation of thermal structure in the upper 100 meters or so of the sea. For example, intermittent wind mixing would be more likely to cause fluctuations of surface temperature in summer when the thermocline is typically shallow than in winter when a deep isothermal surface generally prevails.

Another aspect of the question which deserves closer scrutiny is the descriptive accuracy of the observed sea temperature anomalies. Some of the anomalous features found on the 10-day-mean charts used in the present study may be transient phenomena, possibly due to meandering currents, particularly in regions of strong horizontal temperature gradients. If the magnitude of such short-period fluctuations were large, they would obscure the characterization of month-to-month or longer-period fluctuations.

It is apparent that a quantitative accounting of anomalous temperature changes in the sea still lies ahead. However, promise of accelerated progress is offered by pending developments in instrumentation and new interest in oceanography. These can reasonably be expected to provide better information on the velocity and thermal structure in the upper layers of the sea, as well as improved observational coverage for evaporation, precipitation, cloud cover and radiation, and more accurate determinations of momentum transfer due to wind stress. All of these factors are probably significant in the formation of sea temperature anomalies.

REFERENCES

Namias, Jerome, Recent seasonal interactions between North Pacific waters and the overlying atmospheric circulation, *J. Geophys. Research, 64,* 631–646, 1959.

U. S. Hydrographic Office, *World Atlas of Sea Surface Temperatures (H.O. 225) 2nd ed., 1944.*

(Manuscript received October 14, 1960.)

30

THE FISHES OF RICHMOND GULF, UNGAVA, CANADA[1]

ROBERT L. EDWARDS

Biological Laboratory, Bureau of Commercial Fisheries, Woods Hole

INTRODUCTION

THIS REPORT is based on material collected during the 1953 R/V *Lemming* Expedition to Richmond Gulf. This expedition was financed principally by the American Philosophical Society (Penrose Fund) with additional assistance from the Geological Society of America, the Woods Hole Oceanographic Institution, and the American Academy of Arts and Sciences. The 1953 trip was primarily concerned with the general ecology of the Richmond Gulf area, both land and water.

The research was accomplished from the R/V *Lemming,* a surplus Navy whaleboat, modified into a small oceanographic research vessel. In addition to fish, large collections of small mammals, marine mollusks, and other invertebrates were made. Sufficient temperature, salinity, and depth data were obtained to present a clear picture of the marine environment of Richmond Gulf during the summer months. Dr. J. Lockwood Chamberlin[1] and the author collected all of the data and material discussed.

RICHMOND GULF

Richmond Gulf (fig. 1) is a large triangular body of essentially marine water on the eastern side of Hudson Bay. It is about 30 miles long on its western edge and approximately 20 miles wide. It is deepest along its western side with depths to at least 70 fathoms. The eastern edge is generally shoal. Navigation amongst the small islands was a hazardous business even with a shallow draft vessel, although one could reach almost any general area with the R/V *Lemming* (draft 4 feet) with proper care and navigation.

The gulf is connected with Hudson Bay by a narrow channel, the Hazard, at its southwestern corner. At its narrowest, the Hazard is about 300 yards wide and probably nowhere deeper than about 60 feet. On two transects made with the R/V *Lemming,* the depths recorded here were 30 and 48 feet. Tracings of the depths recorded by echo-sounder on these two trips through the Hazard are presented in figure 2.

HYDROGRAPHY

Numerous rivers enter Richmond Gulf, especially along its eastern edge (see fig. 1). The influx of this relatively warm fresh water in the spring and summer decreases the salinity of the surface waters and raises its temperature. Average summer temperature and salinity data are presented in table 1. Conditions in Richmond Gulf differ from those in Hudson Bay in two significant aspects. First, there is no clearly defined thermocline in neighboring Hudson Bay water. Second, temperatures drop rapidly to values less than zero below 200 feet in Richmond Gulf. While it drops similarly in Hudson Bay, it does not reach these sub-zero values so quickly.

Some typical bathythermograph traces are presented in figure 3 to illustrate the temperature depth relationships observed. It would appear that the cold, relatively saline water entering Richmond Gulf during the winter months is not rapidly flushed out during the summer months. The layer of relatively fresh water on the surface, the thermal stratification, and the depth threshold of the Hazard would all contribute to the trapping of this cold water. These conditions are reminiscent of similar conditions observed by others in arctic fiords where the entrance is shallower than the fiord proper.

Richmond Gulf is not, however, stagnant in the deeper holes. Even the deepest areas had an epi-, and an infauna that was thriving if not populous. This is not really surprising. The turbulence of water entering Richmond Gulf just beyond the Narrows of the Hazard is legendary and undoubtedly provides for at least minimal exchange of even the deepest water.

BOTTOM TYPES, CONDITIONS AND ASSOCIATED INVERTEBRATES

SHALLOW WATER, 0–25 FEET

The shallowest waters, with temperatures of 8 to 15° C. and salinities of 15 to 21 parts per

---

[1] Contribution No. 1109 from the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

PROCEEDINGS OF THE AMERICAN PHILOSOPHICAL SOCIETY, VOL. 105, NO. 2, APRIL, 1961

Reprint *Printed in U.S.A.*

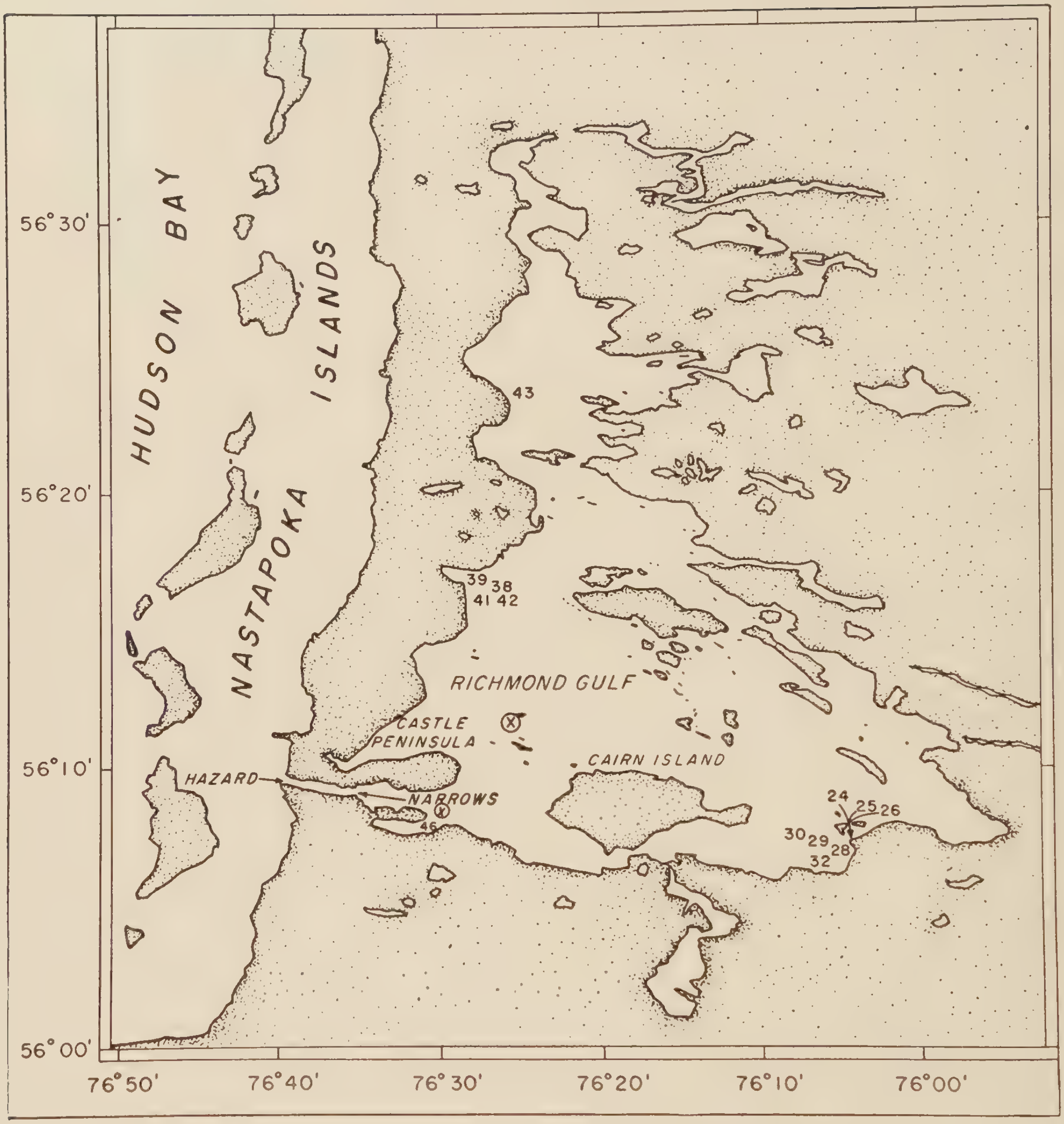

HUDSON BAY
NASTAPOKA ISLANDS
RICHMOND GULF
CASTLE PENINSULA
CAIRN ISLAND
HAZARD
NARROWS
43
39
38
41
42
46
24
25
26
30
29
28
32
56°30'
56°20'
56°10'
56°00'
76°50'
76°40'
76°30'
76°20'
76°10'
76°00'

FIG. 1. Stations mentioned in text where fish were collected in Richmond Gulf, summer of 1953. X indicates otter trawl stations at which fish were not collected.

thousand, usually support thriving communities of fucoid algae and mollusks, depending on the bottom type and the amount of molar action. The bottom may be bare rock, underwater talus, boulders, gravel, sand, clay, or mud.

Where streams and rivers enter, it is usually sand and/or gravel. Off the beaches, which are only a small part of the coast line, the sand and gravel are succeeded by clay and mud. The greatest part of the coast line is bare rock and talus, and the bottom in these areas is usually similar.

Sand and gravel bottoms in relatively shallow water usually had a thriving community of *Mytilus, Mya, Macoma, Buccinum, Strongylocentrus,* and fucoid algae as obvious members

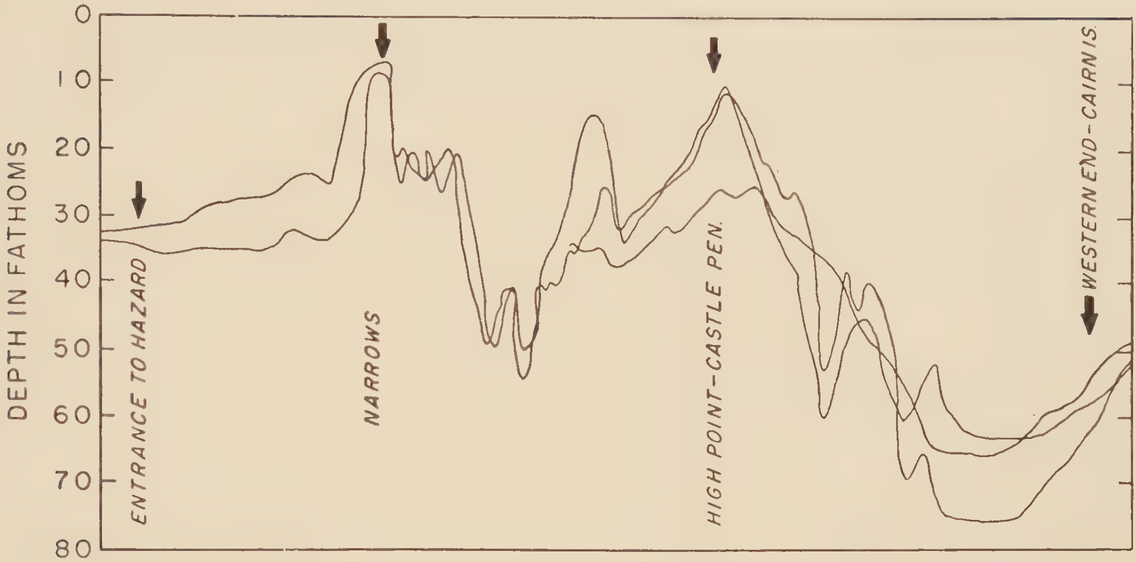


FIG. 2. Echo sounder traces from Hudson Bay entrance of Hazard to Cairn Island, Richmond Gulf. Total distance about 10 miles.

of the fauna and flora. The plain rock bottoms supported little else than the sea urchin, whatever the depth.

MID-DEPTHS, 25–150 FEET

The waters referred to here as the mid-depths have temperatures above 0° C. and salinities of 22 to 26 parts per thousand. The bottom is usually clay or gray and/or brown muds. Rock, talus, and boulders were encountered only where the steep cliffs made up the shore line or where there there were sharp changes in the bottom topography.

The middle depth muds supported extensive populations of invertebrates. The mollusks were represented by species of *Astarte, Trichotropis, Macoma, Portlandia, Pandora, Thracia, Buccinum,* and others. Small decapod shrimp of several genera were present as well as the large isopod, *Mesidothea.* The crinoid, *Heliometra glacialis,* was occasionally collected on these bottoms. Starfish were common and included species of the genera *Solaster, Ctenodiscus, Pteraster, Leptasterias,* and *Ophiura.* Polychaete worm tubes were common. In certain areas, a very large worm, probably *Echiurus,* was an abundant member of the bottom fauna.

TABLE 1

AVERAGE TEMPERATURES AND SALINITIES OF RICHMOND GULF, AUGUST AND SEPTEMBER, 1953

Averages at depths in feet, salinities to the nearest tenth of $^0/_{00}$ and temperatures to nearest 0.5° C.

Depth	S $^0/_{00}$	° C.
0	17.00	10
25	21.90	8
50	23.00	5
75	23.80	3
100	24.80	2
125	25.10	1.5
150	26.00	0.5
200	26.90	0.0
300	27.00	−0.5

DEEP WATER, MORE THAN 200 FEET

This deep water characteristically had temperatures at and below 0° C. The salinities were at least as great as 27 parts per thousand. The bottom in these deep areas is usually red or red-brown mud. None of the bottom samples collected had an H_2S odor. There was not an abundant infauna, and the epifauna was certainly depauperate.

The ubiquitous *Portlandia* occurred, along with *Nucula, Thyasira,* and *Buccinum.* Worm tubes were relatively common. Except for an occasional *Ophiura,* starfish did not occur on these muds.

STATION LIST AND GEAR

A list of the stations where fish were collected is presented in table 2. Data concerning these stations pertinent to this report are included.

We usually depended on the otter trawl to collect fish. Our trawl was a scaled down model of the standard "german-type" trawl used in commercial fisheries. It was about fifteen feet long with a spread of eight feet between the otter boards. The cod end mesh was one inch. The otter boards were frequently upset on the rough bottom and many tows were accordingly failures. The standard towing time was five minutes. Gillnets with one- and three-inch stretched mesh proved to be very useful in well-protected places. Much of the Richmond Gulf area, however, is too open, too rough, and too subject to strong winds to use gillnets effectively. We occasionally hand lined for fish when we were penned up in harbor. The dipnet was used at night from time to time to collect the fish and invertebrates that gathered in the light of our lanterns.

Only minimum numbers of the larger species of fish were saved to conserve space and preservative. As is usually the case, this decision was later regretted.

A small aquarium was carried on board into which we placed specimens for observation. When time permitted, color notes were made of living material.

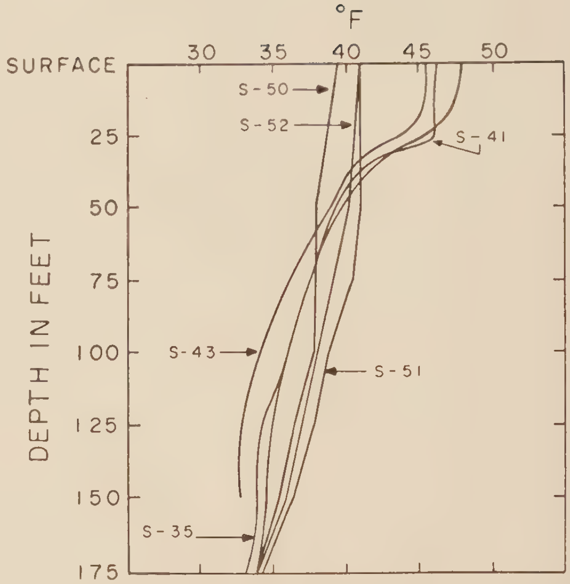


Fig. 3. Comparative bathythermograph traces from Richmond Gulf (Stations 35, 41, and 43) and Hudson Bay (Stations 50, 51, and 52).

ANNOTATED LIST OF SPECIES

The remarks contained in this list are based on the material collected and preserved and on material examined in the field. Only the preserved specimens are listed in the material examined. All of the material will be deposited in the Museum of Comparative Zoology, Cambridge, Massachusetts.

Raja radiata Donovan
Prickly Skate

Material examined: One immature male, 117 mm., and numerous egg cases from station 46.

TABLE 2

Stations where Fish were Collected, with Pertinent Data, August and September, 1953
HL = handline, GN = gillnet, DN = dipnet, OT = otter trawl

Station No.	Depth in feet	Date	Gear	Bottom	Temp. ° C.	Location
24	0	31 Aug.	DN, GN	Sand	9	56°07.5′ N. 76°04′ W.
24b	12	7 Sept.	OT, GN	Rocky	11	56°07.5′ N. 76°04′ W.
25a	15	31 Aug.	HL	Talus	7	56°07.5′ N. 76°04′ W.
25b	50	9 Sept.	HL	Talus	7	56°07.5′ N. 76°04′ W.
—	0	9 Sept.	DN	Talus	12	56°07.5′ N. 76°04′ W.
26a	40	1 Sept.	OT	Gray-brown mud	1.9	56°07.5′ N. 76°04′ W.
26b	50	2 Sept.	OT	Gray-brown mud	1.9	56°07.5′ N. 76°04′ W.
28c	0	22 Sept.	DN	Sand	3.3	56°07′ N. 76°04′ W.
29c	50	5 Sept.	OT	Gray-brown mud	2.1	56°07′ N. 76°06′ W.
30a	60	2 Sept.	OT	Brown mud and boulders	5.0	56°07′ N. 76°05′ W.
31b	40	5 Sept.	OT	Brown mud	5.7	56°07′ N. 76°04′ W.
38	230	9 Sept.	OT	Brown mud	−0.3	56°17′ N. 76°28′ W.
39a	0	11 Sept.	DN	Sand	5.7	56°17′ N. 76°28′ W.
41c	300	17 Sept.	OT	Red-brown mud	0.0	56°17′ N. 76°27′ W.
42a	350	17 Sept.	OT	Red mud	−0.4	56°17′ N. 76°27′ W.
43a	150	19 Sept.	OT	Brown mud and clay	0.3	56°24′ N. 76°27′ W.
46	90	26 Sept.	OT	Clay	2.2	56°08′ N. 76°31′ W.

This species was well known to the local Indians and Eskimos who have caught it while fishing for cod. They describe it as reaching lengths of about 18 inches.

Coregonus (*Leucichthys*) *artedi* (*Le Sueur*)
Cisco

Material examined: 3 specimens from station 24b.

Notes: The cisco was to be seen everywhere along the shore line. Although many specimens were collected, most of them were sacrificed to the frying pan to relieve our otherwise monotonous diet.

Scales from 15 specimens varying in length from 225 to 246 mm. (fork length) were examined for annuli. All had what appeared to be well-defined annuli, and all were in their fourth summer if the writer properly interpreted the scales. Dymond (1933) also determined that fish of this size from Hudson Bay were of this age. It is notable that all of the fish that we collected were in the size range mentioned above.

Gadus m. ogac Richardson
Ogac

This cod was frequently seen. The material examined was all as previously described by various authors. We collected only a few specimens to verify the identification.

It was locally abundant. The Eskimos apparently understood the winter movements of this fish, and at this season fished for it through the ice. Mrs. George Papp, wife of the free-trader in Richmond Gulf, knew of a few places to catch ogac. That she could catch large quantities was demonstrated to Chamberlin and myself when, with two visitors, she caught about 300 pounds one morning in the neighborhood of our station No. 26. The fish were generally large, running about 18 to 24 inches in length. Chamberlin and I were notoriously unsuccessful in making any such catch ourselves.

The few cod that we did catch had been feeding largely on fish, especially *Ammodytes hexapterus.* One specimen, 23 cm. in length, was in its third summer (two annuli plus a zone of further growth), while another, 29 cm. long, was in its fourth summer. Needless to say, this is slow growth for a codfish.

Boreogadus saida (Lepechin)
Polar Tomcod

Material examined: 18 specimens from stations 26a, 38, 41c, 42a and 46.

Size: Largest specimen 163 mm., smallest specimen 87 mm. Most of the specimens averaged just over 100 mm. fork length.

Notes: The polar cod was obviously a fish of the greater depths in Richmond Gulf. The greatest number of specimens (12) were obtained at our deepest station where the water temperature was significantly below zero.

All of these fish had a few scales in the pectoral fin area. An annulus could not be detected on any of the scales. These fish were smooth to the touch as none of the scales had yet developed the bony tubercles.

Color: Very sketchy color notes in my log state that this fish was a "steely greenish blue above, whitish below."

Gasterosteus aculeatus Linnaeus
Two-spined Stickleback

Material examined: Station 39, 18 specimens, 52 to 67 mm., aver. 56 mm. Tide pool, 17 specimens, 20 to 26 mm., aver. 22 mm.

Notes: The two-spined stickleback was observed anywhere on the gulf that we anchored, collecting in small numbers at the surface in the light of our lanterns. They were usually busily engaged in feeding on the gammarids that were also attracted to the light.

Every tide pool and almost every puddle in the spray zone that was examined had large numbers of young two-spined sticklebacks.

Pungitius pungitius pungitius (Linnaeus)
Ninespine Stickleback

Material examined: Station 39, 1 specimen, 45 mm.

This stickleback was observevd and collected in numbers in James Bay and Hudson Bay proper. It seems likely that it is more abundant in Richmond Gulf than our collections indicate, and that we somehow missed it.

Ammodytes hexapterus Pallas
Sand Launce

Material examined: 49 specimens from stations 24, 25, 26a, 27 and 39. There appeared to be two general size categories, the first averaging 65 mm., the second averaging 93 mm.

Remarks: Our material has been assigned to the species *hexapterus* Pallas on the basis of the vertebral numbers. Five specimens from each of three lots were examined, and all fish had 68 vertebrae except two which had 70 and 71 vertebrae. That this species was to be expected in the Hudson Bay area has been pointed out by Walters (1955).

Notes: From the standpoint at least of the casual observer, the sand launce is the most abundant fish in Richmond Gulf. It may be observed in large schools wherever the bottom is sandy. At night schools of this fish collected in the light cast by our vessel. They have been observed in number at low tide, right at the water's edge, burying themselves in the sand as the waves receded and left them stranded. That this activity was not without its hazard was evidenced by the large numbers of sand launces found dead along the strand line during these periods. Indian children were observed gathering these fish when they were to be found at the water's edge.

The sand launce was eaten by *Myoxocephalus quadricornis* and *Gadus m. ogac.* These two fish frequently had their stomachs and even their mouths filled with this species. Chamberlin examined some seal stomachs at Great Whale River in the winter of 1954 and found their stomachs packed with *Ammodytes.*

Most of our material was collected with a dipnet. Chamberlin dredged one specimen up in the summer of 1950 when he was collecting mollusks in some sandy bottom. The material collected at station 24 consisted of launces that gilled themselves in the hardware cloth liner of our bottom dredge one night when it was hanging over the side at the surface.

Aspidophoroides olriki Lütken
Arctic Sea-poacher

Material examined: Three specimens from stations 38 and 46.

Color: Generally white on sides and underneath. Brown line around snout dorsally, extending obliquely under eye to opercle. Two oblique brown bars extending up from the base of the pectorals more or less outlining a diamond-shaped light brown area on the top of the head. Dorsal milky white or transparent with brown bands (color in rays). Caudal with dark brown basal spot and terminated with a similarly colored band.

Icelus spatula Gilbert and Burke
Two-horned Sculpin

Material examined: 19 specimens from stations 38, 41c, 42a and 46.

Size: Largest female 117 mm., largest male 102 mm. Eight specimens measured from 70 to 75 mm. in length.

Notes: The two-horned sculpin was apparently relatively common in the deeper water. It was usually taken along with *Boreogadus saida, Lumpenus medius,* and *Careproctus reinhardi.*

Color: Body and fins generally transparent-whitish. Fins with spotty horizontal bands of light brown. Area including first three rays of pectoral fin white. Two large brown spots below eyes. Two darker brown "bars" on back at level of soft dorsal. Body sparingly "square" spotted with light chocolate brown. Base of caudal fin with brown patch. The color of the gills and black eyeball obviously due to general transparency of fish. Figure 201, page 360 of Andriashev (1954) is an excellent presentation of the pattern seen in the Richmond Gulf specimens.

Gymnocanthus tricuspis (Reinhardt)
Staghorn Sculpin

Material examined: 13 specimens from stations 26b, 28c, 31b.

Size: Largest female 222 mm., largest male 211 mm. Smallest specimens collected were 38 and 42 mm. in length. Six specimens measured from 81 to 145 mm.

Meristics: D XI, 15–16, A 16–18, P 17–18.

Notes: This is an exceedingly difficult species to deal with. I have referred it to *tricuspis* with misgivings about the separateness of the species *tricuspis* and *galeatus.* The history of sculpin systematics has been one of ever-increasing awareness of the morphological plasticity of this genus and of consequent synonymizing of apparently good species as more material becomes available.

Dunbar and Hildebrand (1952) have already detailed the variation in number of bony tubercles on the head of this species. Some of the specimens examined from Richmond Gulf are exactly as pictured in Andriashev (1954: fig. 208–1, page 373), while others lack figured bony tubercles entirely.

TABLE 3

Summary of Meristic Variation in *Gymnocanthus tricuspis* in Arctic and Subarctic North America

	Labrador (Backus, 1957)	Hudson Bay (Vladykov, 1933 and Edwards)	Western arctic America[1]
1st dorsal spines			
Mean	11.2	11.0	10.7
Range	X–XII	X–XII	X–XI
No. of specimens	119	36	55
2nd dorsal rays			
Mean	15.7	15.7	15.2
Range	14–17	15–17	15–17
No. of specimens	118	36	55
Anal rays			
Mean	17.8	17.4	17.3
Range	15–19	17–19	16–18
No. of specimens	119	36	55
Pectoral rays			
Mean	18.7	17.8	18.8
Range	17–21	17–18	17–20
No. of specimens	119	6	55

[1] Based on data presented by Andriashev, 1954, 369, for the Laptev Sea.

Fin ray counts certainly indicate that Richmond Gulf specimens are *tricuspis.*

None of our specimens have a "tricuspid" opercular spine. This spine varies greatly, usually bearing two accessory branches directed dorsally. The proximal branch is often bifid. One specimen had only one dorsally directed branch. The spine of the two smallest specimens was gracefully curved upwards as reported previously by Dunbar and Hildebrand (1952).

The interorbital space also varied greatly in width, varying from 18 to 47 per cent of the horizontal diameter of the eye. Although my sample was small, this variation did not appear to be a matter of sex.

All of the females (four) over 190 mm. had well-developed eggs (diameter about one mm.) in the ovaries.

Color: The following color notes of a small, 81 mm., specimen from station 28c were made: Generally light brown with head back to pectorals a brighter orange brown. Dark chocolate brown bar extending from snout to eye and onto the opercle. Three similarly colored vertical bars on the body, the first under the first section of the dorsal fin, the second under the anterior edge of the second section of the dorsal, and the third just behind the dorsal. A white bar, checkered with black, extended from the base of the pectoral fin to the base of the caudal fin. Belly generally a clear white. Ventral portion of trunk transparent. Pectoral fin yellowish at base, white posteriorly. Four bright reddish-brown bands of color across the pectoral, the color principally in the fin rays. First part of dorsal banded from top to bottom with a relatively broad reddish brown band, a white band, another reddish brown band and a last white band. As in the pectoral, this color was mostly in the fin rays themselves. Second part of dorsal (soft rays) with three such bands of reddish brown, with less white color in between. Pelvic and anal white. Caudal with three vertical bands of reddish brown.

Myoxocephalus quadricornis (Linnaeus)
Four-horned Sculpin

Material examined: 7 specimens from station 24. Two specimens were also available from Fort George on the east coast of James Bay.

Size: Largest male 278 mm., largest female 263 mm.

Notes: This handsome sculpin is always present in those shallow water areas where *Mytilus* and fucoid algae abound. It was frequently taken in numbers in our shallow gillnet sets and never in otter trawl sets in depths greater than 40 feet. Richmond Gulf four-horned sculpins are, as elsewhere, restricted to shallow waters of low salinity.

TABLE 4

Summary of Meristic Variation in *M. quadricornis* in Arcic and Subarctic North America

	Labrador (Backus, 1957)	Hudson Bay (Vladykov, 1933 and Edwards)	Western arctic America (Walters, 1955)
1st dorsal spine			
Mean	7.9	7.9	7.9
Range	VII–IX	VI–X	VI–X
No. of specimens	9	134	116
2nd dorsal rays			
Mean	14.7	14.6	13.8
Range	14–16	13–17	11–15
No. of specimens	9	134	114
Anal rays			
Mean	14.4	14.7	13.6
Range	14–16	13–17	12–16
No. of specimens	9	134	111
Pectoral rays			
Mean	15.5	15.6	16.3
Range	15–16	15–17	15–18
No. of specimens	9	28	98

The males and females collected in September were nearly ripe. Their stomachs almost invariably contained gammarids. A few specimens were feeding on sand launces.

Color: This sculpin is most distinctly colored, especially during the breeding season. The following color notes were made from several male specimens collected early in September: General color above brown to dark greenish brown with a mottling of light cream or very light brown. Occasional specimens are very light green-brown above. Rays of all fins cream to light brown, the tissue between a dull black. Some specimens had the rays of the pelvic fin pink, in others the pelvic fin rays and the tips of the pectoral rays were yellow to yellow-orange. Bony "combs" on head dirty white. Belly and sides bright canary yellow. Ventral part of gill cover frequently bright pink. Membranous portion of jaw rosy. Ventral portion of trunk white.

Myoxocephalus scorpius (Linnaeus)
Sea Scorpion

Material examined: 4 specimens from stations 24 and 30a.

Meristics: D IX-X, 15–16, A 13–15, P 16–17.

Notes: This species was relatively common in shallow-water areas with sandy and bare-rock bottoms where we caught many with handlines in the summer of 1950. Only one specimen was taken in relatively deep water in 1953 (station 30a). One was taken in a gillnet in 7 feet of water. During the summer months at least *scorpius* may be frequently found in low salinity, shallow water.

Specimens collected in September were approaching ripeness; the eggs of one female exceeded one millimeter in diameter. Their stomachs contained the remains of gammarids, isopods, and fish.

TABLE 5

Summary of Meristic Variation in *M. scorpius* in Arctic and Subarctic North America

	Labrador (Backus, 1957)	Hudson Bay (Vladykov, 1933 and Edwards)	Western arctic America (Walters, 1955)
1st dorsal spines			
Mean	10.0	10.3	10.4
Range	IX–XI	IX–XII	IX–XI
No. of specimens	241	49	29
2nd dorsal rays			
Mean	16.9	16.5	15.1
Range	15–19	15–18	14–16
No. of specimens	241	49	27
Anal rays			
Mean	13.7	13.2	11.8
Range	12–16	12–15	11–14
No. of specimens	241	49	25
Pectoral rays			
Mean		17.3	17.4
Range		16–18	16–18
No. of specimens		21	29

Eumicrotremus spinosus (Muller)
Spiny Lumpfish

Notes: One small specimen, about 10 mm., was taken by dipnet at night on station 39a. We put it in a beaker with some gammarids to watch it for a while. The gammarids disposed of all but a few remnants in just a few minutes while we were occupied dipnetting. Fortunately, there was no doubt as to its identity.

Careproctus reinhardi (Kroyer)
Jellyfish

Material examined: 3 specimens from stations 29c and 38, measuring 40, 60 and 68 mm.

Notes: Unless one has been previously prepared, this fish presents an unbelievable and shocking first appearance. When our first specimen dropped on the deck, we thought it was a partially digested fish from the stomach of a cod. On closer examination, it proved quite lively, and we kept it in the aquarium for a day, examining it with great interest.

This tadpole-shaped fish is surrounded by a clear, gelatinous layer that is particularly thick over the trunk. Most of the dorsal and anal fins are included in this sheath forward. The pectorals and caudal are free. The various organs and major nerves and blood vessels were easily traced in our largest specimen (68 mm. long). The only color in the fish was the normal color of the internal organs, black eyeballs, red muscles, brownish liver, etc.

The local Eskimos and Indians are familiar with the species and say that it reaches lengths of up to 6 inches or more. Eskimo children play a game with it (described by two creditable witnesses). It is placed on the bare arm to which it apparently fastens with its sucker. The child then runs around with it, and the other children attempt to snatch it away.

It is reported caught in fair numbers when fishing for cod through the ice in winter.

Our material has been referred to *reinhardi* (Kroyer). Until large collections of fish of this genus from arctic and boreal areas are available, the status of many of the species in the genus will be questionable. The Richmond Gulf specimens had about 52 dorsal rays, 48 anal rays, and 30 pectoral rays. The eye is about 20 per cent of head length and slightly larger than the ventral sucker. The pectoral fin was not obviously notched. The rays of the lower lobe were separated distally and barely extended beyond the anus. The anus was situated well forward, close to the ventral sucker. The ventral sucker was squarish, not triangular, and situated well forward under the eye. There were no "prickles" on the body, such as those reported by Backus (1957) for *C. longipinnis* Burke from Labrador. The extent descriptions of *longipinnis* are sufficiently broad, however, to include our material "prickles" or no, as are those of *C. reinhardi* (Kroyer).

Lycodes reticulatus Reinhardt
Reticulated Eelpout

Material examined: 2 specimens from stations 26a and 41c, measuring 95 and 105 mm.

Notes: Each of these specimens had scales with a few circuli, no annuli.

Color: General body color a warm orange with a pink overtone. Dorsal fin dark brown barred, the bars extending down onto body and breaking up into irregular vertical lines. One fish had 7 such bars, the other 10. Andriashev's (1954) figure 156, page 285, of *L. rossi* shows a similar pattern, especially on the head. Figure 158, page 287 (*op. cit.*) of *L. reticulatus* lacks the reticulations on the head that were so obvious on our younger specimens.

Lumpenus medius Reinhardt
Stout Eelblenny

Material examined: 10 specimens from stations 26a, 29c, 30a, 32 and 38.

Size: Largest specimen 133 mm., smallest 70 mm.

Notes: This small fish was captured frequently enough in our relatively large mesh otter trawl to suggest that it may have been quite common.

It is easily distinguished from *fabricii* by the manner in which both the dorsal and anal fins are joined to the caudal. *L. fabricii* does not have its dorsal and anal fins so joined with the caudal; rather they end just short of the caudal.

Color: Body generally pink-transparent. Spotted or mottled with light brown. Irregular black spot behind eyes. Caudal and dorsal faintly banded with brown. Underneath head and belly milky white.

Lumpenus fabricii (Cuvier and Valenciennes)
Slender Eelblenny

Material examined: 4 specimens from station 38, measuring 163, 163, 170 and 192 mm.

Notes: Despite their length, these are very slender fishes. It is probable that they are much commoner than the data indicate, since they could easily escape through the meshes of the trawl.

DISCUSSION

Three species of fish are added to the Hudson Bay list in this report—*Ammodytes hexapterus, Lumpenus medius,* and *Careproctus reinhardi.* None of this material does any violence to the generally accepted opinion that Hudson Bay fishes re-entered the area from Atlantic refugia following the Wisconsin glaciation.

The presence of *A. hexapterus* in Hudson Bay was predicted by Walters. This euryhaline species could easily have made its way from the western Canadian arctic into Hudson Bay at almost any time. While the vertebral counts do indicate a western origin for this population, it must be remembered that vertebral numbers are subject to modification by the environmental temperatures and that the vertebral numbers of our material may merely be the result of temperature differences between Hudson Bay and the rest of the eastern Canadian arctic (where *Ammodytes dubius* occurs).

The meristic data available for *G. tricuspis, M. quadricornis,* and *M. scorpius* are presented in tables 3, 4, and 5. It is to be regretted that little further data are available. *M. quadricornis* and *M. scorpius* from Hudson Bay are similar meristically to fish from Labrador, and are quite different from the fish of western arctic America. In general these remarks apply as well to the *G. tricuspis* population from Hudson Bay. In this case the pectoral fin ray count appears anomalous but it is based on only six specimens.

There is a suggestion of trends in these data that someone in the future with access to good collections of *Myoxocephalus* from the arctic should look into, with respect to the interrelationships of populations, the relation of meristics to water temperatures, and with respect to the manner in which the numbers of rays vary in one fin with respect to another. It will be observed in the *Myoxocephalus* meristic data for both species that the total counts of rays tend to be greater for Labrador individuals than for Hudson Bay specimens, and that Labrador and Hudson Bay counts are generally higher than are those of western arctic American material. There is a suggestion that the pectoral rays counts vary in the opposite direction.

The fauna of Hudson Bay, as collected in Richmond Gulf and elsewhere, quite clearly appears to be derived from the Atlantic side. The present writer agrees completely with the remarks on this subject expressed by Walters (1955: 353).

The Richmond Gulf area merits further study of all groups. It is especially interesting from the hydrographic point of view. It is, at least, a convenient place to work in, having depths in excess of 70 fathoms and being relatively protected from the otherwise extremely harsh weather conditions that one experiences on Hudson Bay proper. The fauna includes many species generally considered as indicators of true arctic conditions as well as quite typical subarctic and even boreal species. It is apparent that there are often limitations of the arctic environment besides sub-zero temperatures, and these problems could be profitably pursued in Richmond Gulf.

The following species were observed and/or collected in the shallow, low salinity water of Richmond Gulf:

Gadus m. ogac
Myoxocephalus quadricornis
Myoxocephalus scorpius
Ammodytes hexapterus
Gasterosteus aculeatus
Pungitius pungitius
Mallotus villosus
Eumicrotremus spinosus
Salvelinus alpinus
Coregonus (*Leucichthys*) *artedi*

The following marine species were collected in water above 0° C. in salinities varying from 22 to 26 parts per thousand.

Raja radiata
Gadus m. ogac
Boreogadus saida
Lumpenus fabricii
Lumpenus medius
Lycodes reticulatus
Gymnocanthus tricuspis
Icelus spatula
Myoxocephalus scorpius
Aspidophoroides olriki
Careproctus reinhardi

The following species were collected in water near or below 0° C. and in salinities of 27 parts per thousand or greater.

Boreogadus saida
Icelus spatula
Careproctus reinhardi

REFERENCES

Andriashev, A. P. 1954. Fishes of the northern seas of the SSSR. Moscow and Leningrad, Acad. Sci., SSSR.

Backus, R. H. 1957. The fishes of Labrador. *Bull. Amer. Mus. Nat. Hist.* **113**: art. 4.

Dunbar, M. J., and H. H. Hildebrand. 1952. Contribution to the study of the fishes of Ungava Bay. *Jour. Fish. Res. Board Canada* **9** (2).

Dymond, J. R. 1933. Biological and oceanographic conditions in Hudson Bay. 8. The coregonine fishes of Hudson and James Bays. *Contrib. Canadian Biol. Fish.*, N. S. **8** (1).

Vladykov, V. D. 1933. Biological and oceanographic conditions in Hudson Bay. 9. Fishes from the Hudson Bay region (except the Coregonidae). *Contrib. Canadian Biol. Fish.*, N. S. **8** (2).

Walters, V. 1955. Fishes of western arctic America and eastern arctic Siberia. Taxonomy and zoogeography. *Bull. Amer. Mus. Nat. Hist.* **106**: art. 5.

31

Reprinted from THE JOURNAL OF PARASITOLOGY, February, 1961,
Vol. 47, No. 1, pages 125–157.

STUDIES OF THE PHILOPTERIDAE (MALLOPHAGA) FROM BIRDS OF THE ORDER PROCELLARIFORMES

1. THE GENUS *HALIPEURUS* THOMPSON

ROBERT L. EDWARDS

U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries,
Biological Laboratory, Woods Hole, Massachusetts

The Mallophaga of the birds of the order Procellariformes have attracted the interest of entomologists since the time of Fabricius. My own study was initiated when I had the good fortune to acquire a collection of these insects from the American Museum of Natural History. That material, plus an even larger amount from other sources, totaling well over 2,000 specimens, made it possible to revise the generic concepts of the lice of the family *Philopteridae* found on the procellariforms and to revise the sizeable subgenus *Halipeurus*.

This paper revising the genus *Halipeurus* is the first part of several concerned with the lice of the procellariform birds. This paper and the succeeding papers are based in part or in whole on my thesis, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Biology of Harvard University. The papers to follow will be concerned with revisions of the other genera of the family Philopteridae. The final paper in this series will discuss the degree of concomitant phylogeny exhibited between these parasites and their hosts.

METHODS

To be properly studied the lice must be cleared and mounted on microscope slides. The usual technique of clearing in caustic potash and mounting in Canada Balsam is satisfactory but time consuming. A new technique, described by Salmon (1951), using a polyvinyl alcohol, lactic acid, and phenol compound, is much more satisfactory, requires considerably less time, and makes it possible to see the chaetotaxy and subtleties of sclerotization with greater clarity. With a phase microscope, specimens mounted in the polyvinyl alcohol medium show much internal structure formerly destroyed by using KOH. Among the disadvantages of using polyvinyl alcohol is that it does not completely clear the darkly colored material within the alimentary tract, the slides must be examined periodically to fill in the vacuities that occasionally appear under the coverslip, and the medium occasionally hardens with a dispersion of small crystal-like objects in it.

The lice are placed directly in the mixture, regardless of the preservative used. Even dry specimens are satisfactorily re-expanded, although best results are obtained when such material is first soaked a few days in 30 percent alcohol. The various possible solutions are all discussed in Salmon's paper (op. cit.), the most successful mixtures seem to be those with the higher percentages of phenol.

The technique, in addition to clearing well, leaves the general pigmentation more or less unchanged. This is particularly useful in the case of species that have unusually heavy sclerotization.

It is standard procedure on the part of many workers to remove the male genitalia from the lice. In a properly cleared slide this is often not necessary. The genitalia are sufficiently visible when left within the insect to serve their diagnostic purpose, especially since the terminal segments are of such value that the possibility of destroying them outweighs the advantages of removing the genitalia. Removing the genitalia, of course, serves its purpose when more exacting study of the genitalia is required.

Lice may be removed from a bird study skin without damage to the skin if it is in good condition. A blunt dissecting needle thrust under the feathers and then moved out at right angles

---

Received for publication March 28, 1960.

to the shaft of the feathers while lifting them slightly was found to be most effective. If large numbers of lice are on the bird, tapping will dislodge many of them. Lice so taken from skins are often perfect specimens. They tend to be shaken out over a period of years and thus fall to the bottom of the drawer in which the skins are stored. If, subsequently, another bird is placed upon the louse, it may adhere to this bird. Consequently, unless a bird is found with more than a few lice of one species, some doubt exists concerning the true host. One should keep in mind also that the original collector of the bird may not have kept his freshly collected specimens separated from each other, and thus allowed some of the lice to move about from one host to another before they died.

The drawings were made with the aid of a camera lucida attached conventionally to a compound microscope. A low-power ocular (2 ×) was used in conjunction with the high power (44 ×) objective for all drawings in order to keep them at the same scale and sufficiently detailed to cover the wide size range of these lice.

Since the ventral chaetotaxy of the terminal segments was of primary interest, the insects were usually mounted ventral side up on the slide. These species may be determined with a binocular dissecting microscope, providing a magnification of 120 × is possible. Using such a microscope, however, these drawings are oriented correctly only if the insects are mounted ventral side down. The method of mounting actually is a matter of choice, and becomes important only when species with peculiar asymmetrical developments are concerned.

The measurements were made with the aid of an ocular micrometer. Since any mounting medium tends to distort the specimens, the measurements vary in reliability. Because of the more or less inflexible structure of the head, those measurements concerned with its length and breadth are very accurate. Total length and abdomen length are less so, while abdomen width is unreliable unless obviously undistorted specimens are used.

The head ratio and abdomen ratio are computed by dividing the length of each by the greatest breadth.

The following abbreviations are used in the text:

(AMNH) American Museum of Natural History, New York City;
(BMNH) British Museum (Natural History), London;
(GBT) Referring to the collection of Gordon B. Thompson;
(Meinertzhagen) Referring to the Meinertzhagen collection of Mallophaga, in the British Museum of Natural History;
(RLE) Material collected personally, as indicated; and
NV No variation within reasonable limits of measurement.

The host names used are those in Peters' *Check List of Birds of the World,* 1, 1931, unless otherwise noted in the text. All drawings appearing in this paper refer to the genus *Halipeurus.*

ACKNOWLEDGMENTS

For the loan of the material that initiated this study, I am indebted to Dr. C. H. Curran, Department of Entomology, American Museum of Natural History. Since that time he has loaned other material and further aided me in various ways. Miss Theresa Clay, Department of Entomology, British Museum of Natural History, has loaned me comparative material from the British Museum collections and from the Meinertzhagen Collection. Miss Clay has also been helpful on matters taxonomic. Her understanding of the Mallophaga is comprehensive and the discussions that we have had by mail contributed vastly to my understanding of these lice. The late Dr. G. L. Ferris of Stanford University sent me some of Dr. Kellogg's type material and other specimens pertinent to this study. Mr. Gordon B. Thompson loaned me his excellently mounted collection of the subgenus *Halipeurus* and *Trabeculus.* Dr. G. H. E. Hopkins, The Zoological Museum, Tring, loaned me additional material that was collected for him by Mr. H. F. I. Elliot, Administrator of Tristan da Cunha.

The bulk of the material herein discussed was collected personally from museum skins. Mr. James E. Peters, Curator of Birds, Museum of Comparative Zoology, Harvard University, kindly gave me access to the collections of birds. Mr. Charles O'Brien, of the Department of Ornithology, American Museum of Natural History, made collections available to me several times during the past few years.

Dr. K. C. Emerson, presently Lt. Col., U. S. Army, aided me in getting a foundation of systematic knowledge of the Mallophaga in general. The Sigma Xi Society financed a trip to Oklahoma during the summer of 1949 so that I might work personally with Dr. Emerson.

I am particularly grateful to my sponsor, Dr. Frank M. Carpenter, Professor of Entomology, Harvard University. He agreed to guide me in this problem when I was the veriest tyro in Entomology, let alone research in Mallophaga.

The type material resulting from this study has been distributed in such a manner as to give the British Museum (Natural History), the American Museum of Natural History, and the Museum of Comparative Zoology each as complete a set of types and/or paratypes as possible. Additional type material will be deposited in the United States National Museum.

I. BIOLOGY AND ECOLOGY

Ecologically, many of these lice are strongly adapted to restricted niches, i.e., to various localized parts of their bird hosts. Clay (1949) has discussed this aspect particularly well. The elongate lice treated in detail here are adapted to live on the back and wings of the birds. To gain some idea of the ecological diversity of these lice, however, consider the albatross, *Diomedea,* on which the following genera may be found, usually as follows: *Harrisoniella* on the primary wing feathers, *Episbates* on the secondary wing feathers, *Naubates* and *Perineus* on the back and proximally on the wing, *Docophoroides* on the head and neck, and *Austromenopon* (*Menoponidae*) under the wings, and on the breast and belly.

These lice exist in a relatively uniform environment, with a high constant temperature (that of their host) and an abundant food supply (feathers). Their principal enemy seems to be the host. Although they move quickly through the feathers, they must occasionally be brushed off or crushed by the bird's beak.

Transfer from one host to another is presumably largely direct. Mainly, it probably consists of movement from the adult to young, although the lice may migrate at any time that birds come in close contact with one another. It is well known that the *Hippoboscidae* carry Mallophaga about, and while these flies are not known to frequent the procellariform birds, the possibility of that type of transfer exists.

The material at hand indicates that there are only three instars, as in other genera of Mallophaga that have been studied. The length of the period of development from egg to adult is probably about one month; Wilson (1934, 1939) has data on two species infesting chickens which indicates that each instar has a duration of approximately 1 week. Unfortunately, it is almost impossible to obtain living lice of the genera treated here, as the procellariform birds are found typically about the equatorial region and further south. The few species found in the northern hemisphere do not commonly visit the shores of the New England region except under unusual conditions, although small colonies of the storm petrel, *Hydrobates p. pelagicus* (Linn), are known to nest on a few islands off the coast of eastern North America.

Order MALLOPHAGA *Nitzsch*
Suborder ISCHNOCERA *Kellogg*
Family Philopteridae *Burmeister*
Tribe Philoceanini *tribe nov.*

Description: Relatively elongate Philopteridae with broad abdominal buttresses having (usually) well developed anterior and/or posterior medial processes; abdominal tergites sclerotized completely across dorsum, not divided medially in either sex (*Harrisoniella* excepted, with slight medial division); signature not divided medially but sometimes with a gutta, well developed to completely subordinated; genitalia simple, typically asymmetrical, parameres usually subequal and only lightly sclerotized; without complex setal patterns on terminal segments.

Key to the Complexes and Genera of Philoceanini

1.	With relatively small, rounded medial processes; signature usually longer than broad, sometimes with a gutta	(*Philoceanus*-complex) 2
	With relatively bulbous or elongate medial processes; signature usually broader than long, never with gutta, usually considerably reduced	(*Pseudonirmus*-complex) 3
2.	Very slender lice, 8 or more times as long as broad	*Halipeurus*
	Less than 7 times as long as broad	*Philoceanus*
3.	Very large lice, (5–11 mm), basal segment of male antenna with elongate process	*Harrisoniella*
	Not so large	4
4.	Cuticle with obvious 'pebbled' appearance	*Episbates*
	Cuticle not as above, may be either darkly pigmented overall or with buttresses only colored	*Pseudonirmus*

The *Philoceanus*-complex includes the genera *Philoceanus* and *Halipeurus*, each of which is further divided into subgenera and species-groups. The complex occurs on almost all of the procellariforms, with the possible exception of the albatrosses (*Diomedea* and *Phoebetria*). All the species are well colored. The medial processes are usually well developed but not knobbed, elongate, or bulbous. They are all generally heavily sclerotized, and the mid-abdominal segments of the males typically have a heavily sclerotized band across the tergite that is strongly narrowed medially. The signature is well developed and as long or longer than broad. All of the lice are relatively slender and thereby adapted to live on the wings and backs in particular of their hosts.

The Genus Halipeurus *Thompson*

The genus *Halipeurus* herein revised in part comprises a group of slender, mahogany-colored bird lice of moderate size, 3 to 5 millimeters long. They are typically found on birds of the families Procellaridae, Pelecanoididae, and Hydrobatidae, the shearwaters and petrels, the diving petrels, and the storm petrels, respectively. They are usually found on the backs and wings of those birds, being functionally adapted to these areas.

These lice have attracted the interest of several workers in the past 50 years, particularly Launcelot Harrison of the University of Sydney, Australia. Harrison died before he had published much of his findings, the posthumous publishing of a manuscript (1937) revealing that he had accomplished far more than was indicated in this last paper. There are specimens in existence that he labeled, additional evidence that he did have a clear idea of the species involved although he never published their descriptions. Recently, Mr. Gordon B. Thompson has continued research on these lice, and he has published many papers on them. It was necessary that I make arrangements with him to divide this work. At that time I did not have a clear idea of the validity of the various genera involved and it was agreed that I confine my work to the genus *Halipeurus* of which I had a large collection, and that I would leave the genera *Synnautes* and *Naubates* to him. Since that time it has become abundantly clear that *Synnautes* as a taxon would rank no higher than a subgenus, pending more material, and it is so considered in this work. I have not described any new typical *Synnautes,* but have taken the liberty of describing one atypical species that is pertinent to the content of this study.

MORPHOLOGY

The homologies of the various parts of the mallophagan head, long debated, were competently investigated by Symmons (1952). This study and that of Clay (1951) have resulted in a considerably different understanding of the morphology and terminology of the head. These two papers should be referred to by anyone interested in these matters. The terminology used in this paper is for the most part that advocated by Clay (op. cit.).

Head: The head is roughly twice as long as broad, in subgenus *Synnautes* slightly narrower and with straighter lateral margins than in *Halipeurus* (see fig. 2, A and B). It is buttressed laterally, as in the thorax and abdomen, with a heavily sclerotized, internally concave bar. This buttress is made up of three parts: the first, the premarginal carina, on either side of the ante-clypeus, giving support to the ante-clypeus; the second, anterior to the antennal socket, the postmarginal carina; and the last, that of the lateral margin of the parietal area, the marginal temporal carina. Anteriorly, the postmarginal carina arcs medially and then posteriorly on the dorsal surface of the head in the form of a heavily sclerotized band, the dorsal carina. In *Synnautes,* the two paralleling dorsal carinae extend posteriorly to a point approximately midway between the mandibles and the signature, ending abruptly. In typical *Halipeurus,* they continue on to roughly the level of the mandibles, where they again arc and join medially. On the ventral surface, a similar carina marks the ventromedial borders of the clypeus. It extends anteriorly to the level of the ante-clypeus. It may or may not be present in subgenus *Halipeurus,* but is very heavily sclerotized in *Synnautes.* At the posterior end, the postmarginal carina again arcs medially for a short distance. The marginal temporal carina tapers out caudad of the eye, becoming heavy again on either side of the posterior border of the gular sclerite. These last mentioned sclerotizations are sometimes referred to as 'occipital blotches.' The head of a third-instar nymph shows that the clypeus is divided medially prior to adulthood, and the dorsal carinae of adult *Halipeurus* demark this nymphal division.

The anterior plate, or signature, a separate sclerotized area lying between the premarginal carinae, is bordered by a broad hyaline margin anteriorly. Apparently movable, it is attached to the surrounding portions of the head with connective tissue. The exact function is unknown, but it is probably largely sensory. The ventral anterior border of the sclerotized portion is marked with scale-like undulations. Ventrally, just anterior of the mandibles, a soft, flap-like projection, the pulvinus, extends about half-way to the signature. The labium and the knob-like rudiments of the maxillae occupy the area immediately posterior of the mandibles. The rounded gular sclerite is situated between the mandibles and the posterior margin of the head.

The antennae are dimorphic (fig. 1). In typical *Halipeurus* males, the basal segment is approximately twice as long as the second, and varies, depending on the species, from cylindric to bulbous. The third segment is oblique distally, angling the last two segments dorsally and posteriorly, a condition that presumably aids the male in grasping the female during copulation. In the female, the antennae are simple, with the second segment as long or slightly longer than the first. Typical

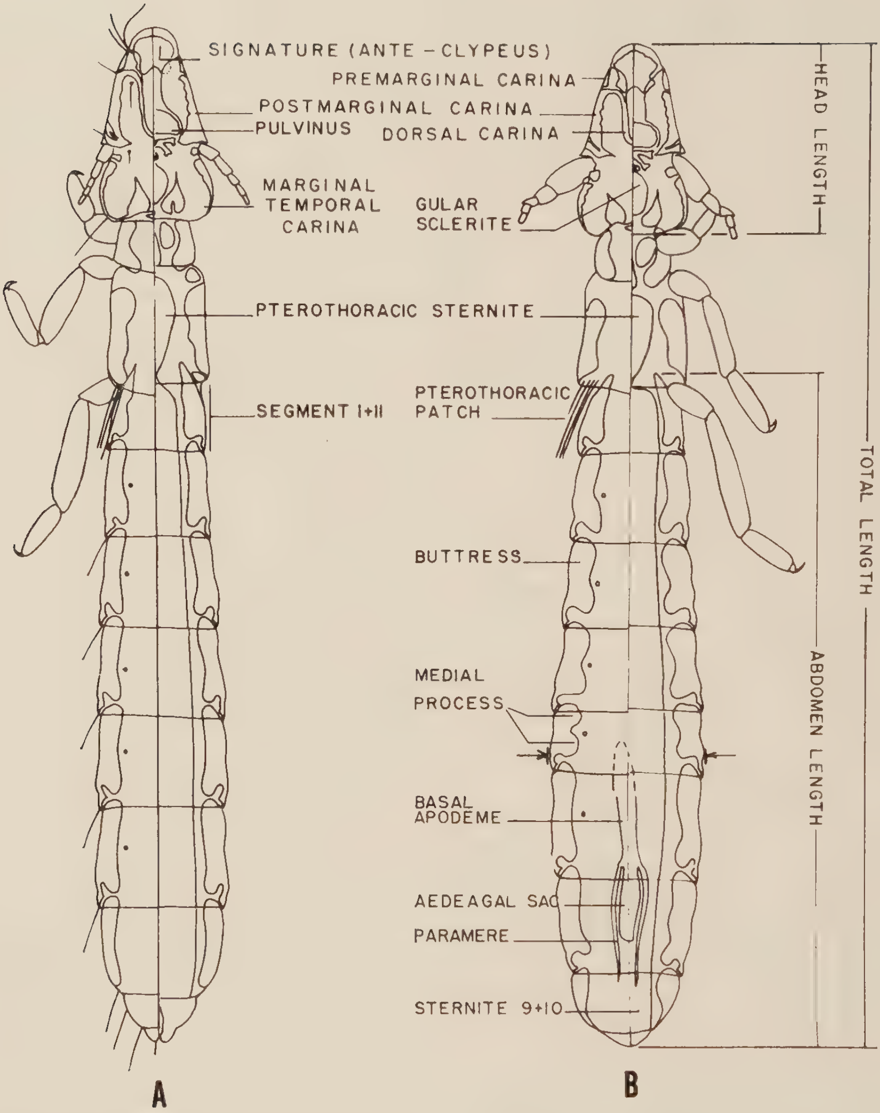

SIGNATURE (ANTE-CLYPEUS)
PREMARGINAL CARINA
POSTMARGINAL CARINA
PULVINUS
DORSAL CARINA
MARGINAL TEMPORAL CARINA
GULAR SCLERITE
PTEROTHORACIC STERNITE
SEGMENT I+II
PTEROTHORACIC PATCH
BUTTRESS
MEDIAL PROCESS
BASAL APODEME
AEDEAGAL SAC
PARAMERE
STERNITE 9+10
HEAD LENGTH
TOTAL LENGTH
ABDOMEN LENGTH
A
B

FIGURE 1. Diagrammatic drawings of typical *Halipeurus* to illustrate the principal terms and measurements. A, dorso-ventral view, female; B, dorso-ventral view, male.

Synnautes males have antennae that vary in much the same manner, but tend to be longer and slimmer.

The chaetotaxy of the head is relatively constant and offers little of taxonomic value. The setae inserted on the signature and the premarginal carina curve gracefully in front of the head and presumably serve as tactile organs.

Thorax: The thorax is typical, consisting of a distinct, relatively narrow, short prothorax, and a united meso- and metathorax, jointly termed the pterothorax. It is about as long as the head in this genus. As in the head, fusion and deletion have simplified the makeup of the thorax, but have also in turn obscured exact homologies.

With the exception of a patch of linearly arranged, close-set setae on the posterior border laterally, nothing is present on the thorax that is significant to this study. The setae mentioned, however, herein referred to as the pterothoracic patch, have some taxonomic interest and are mentioned in the descriptions. In the genus *Halipeurus,* there are usually three of these long setae set in a small unsclerotized area, with a small, stout seta adjoining laterally.

Abdomen: The abdomen is almost twice as long as the head plus the thorax. In the adults, there are nine apparent segments, since morphological segments 1 and 2 and 9 and 10 are fused. There is ample evidence in the nymphal stages that 9 and 10 are so fused in the adult, although none that 1 and 2 are (fig. 2, D and E). In the following discussions, the segments are referred to by their morphological

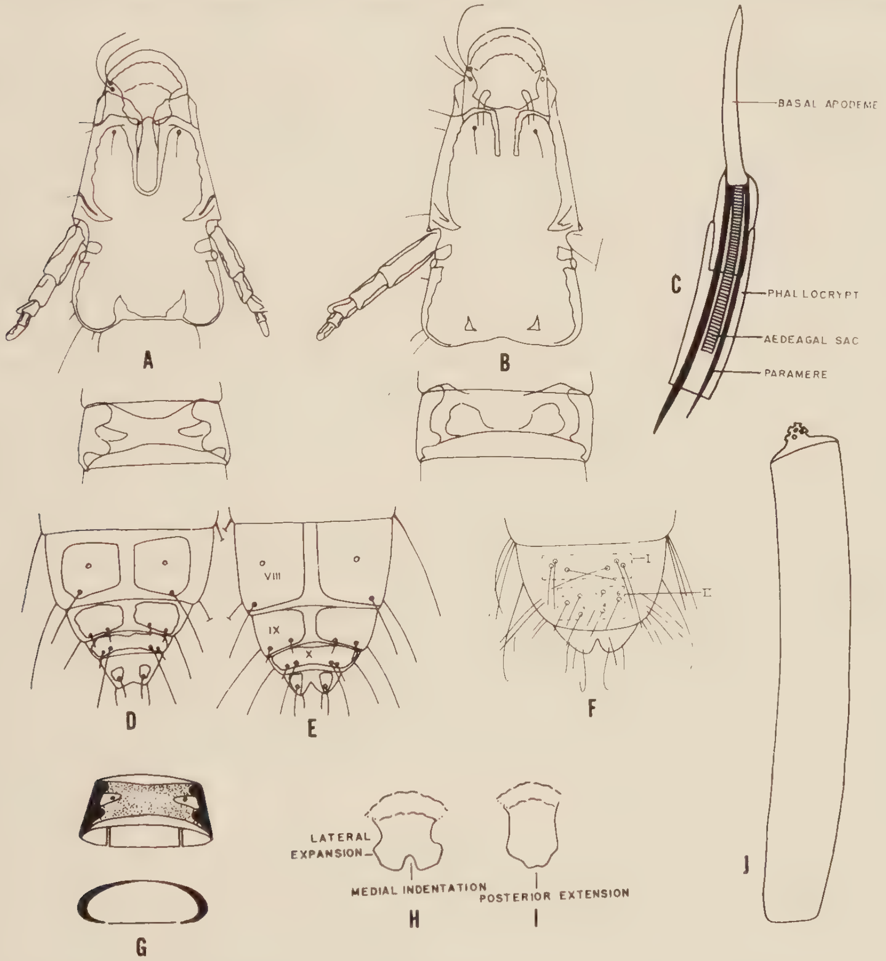


FIGURE 2. A, head and fifth abdominal segment of *H.* (*Halipeurus*) *taxosetus* sp. nov.; B, head and fifth abdominal segment of *H.* (*Synnautes*) *pelagicus* (Denny); C, diagrammatic drawing of male genitalia; D, terminal segment tergites of second-instar nymph; E, terminal segment tergites of third-instar nymph; F, schematic presentation of ventral chaetotaxy of terminal segments of adult male; G, diagrammatic views of abdominal sclerites; H, signature of *'taxosetus'* type, typical of lice from *Puffinus;* I, signature of *'procellariae'* type, typical of lice from *Pterodroma;* J, egg of *H. marquesanus* (Ferris) (cap is distorted).

number, i. e., apparent segment 5 is referred to as segment 6. With the exception of segment 11, each segment is strongly buttressed. These buttresses are relatively narrow in typical *Synnautes* and lack any marked development of medial processes (fig. 2, B). In *Halipeurus,* the buttresses are relatively wide and almost always have medial processes, especially in the middle segments, that involve much of the buttress. A diagrammatic view demonstrating the nature of the abdominal buttresses may be seen in fig. 2, G. The sixth segment is narrow in many species of this genus, allowing the abdomen to flex dorsally at a sharp angle to aid in copulation. This sixth segment retains, more obviously than the rest, the typical sclerotization of tergites of the *Philoceanus*-complex.

The terminal segments 9, 10, and 11 are of considerable interest, since the modifications of sclerites within this area enable one to separate out many of the species quickly. Males are usually more modified than are the females, and for this reason only males are designated as holotypes, a practice that I hope other workers will follow.

There is no doubt that, as mentioned previously, tergites 9 and 10 are fused in the adult, although it is questionable whether a similar condition exists in the sternites. The chaetotaxy of the sternite suggests that it is a result of such fusion, however, and it is considered to be so fused here. For the sake of convenience, the chaetotaxy is divided into two groups, I and II, as indicated in fig. 2, F. Group I remains fairly constant throughout the genus. Group II is often found in the condition figured, but, as the terminal segments are modified, these setae are shifted into other arrangements, and this shifting can be interpreted accurately in most cases.

The fact that the female terminal segment has buttresses suggests that the sclerotized remnants seen in segment 11 of the males are probably reduced buttresses. Typical female *Halipeurus* have a more or less truncate posterior with a rounded medial indentation, while *Synnautes* females have a bifid, pointed posterior, with enlarged setae terminating the buttresses.

The male genitalia consists basically of a pair of variously modified parameres attached proximally to a flat, lightly sclerotized basal apodeme. An aedeagal sac lies between the parameres and is usually only lightly, if at all, sclerotized. The parameres, plus the aedeagal sac, are retracted within an internal, tubular phallocrypt. In some species, at least, there appears to be an endophallus. (Refer to fig. 2, C for terminology.)

The egg is very long and slender (fig. 2, J), with a flat side. Anteriorly, it is obliquely truncate, bearing a lid with an irregular circle of about 15 micropyles, depending on the species.

Genus Halipeurus *Thompson*

Pediculus Linne, *partim,* 1758, Systema Naturae, 10th ed.

Lipeurus Nitzsch, *partim,* 1818, Germar's Magazin, **3**, p. 292.

Esthiopterum Harrison, *partim,* 1916, Parasit., **9**, pp. 21, 26.

Halipeurus Thompson, 1936, Ann. Mag. Nat. Hist., ser. 10, **18**, pp. 40–41. Genotype *Lipeurus angusticeps* Piaget.

Synnautes Thompson, 1936, As above, p. 43.

Halipeurus Harrison, 1937, Australasian Antartic Exped., 1911–14, ser. C, **2**, Pt. 1, p. 31. Genotype *Halipeurus euryphallis,* a nomen nudum.

Naubates Bedford, *partim,* T. Clay, 1940, Brit. Graham Land Exped., 1934–37, **1**, No. 5, pp. 309–310.

Description: Elongate lice adapted to living on the back and proximal parts of wings of *Puffininae* (shearwaters) and *Hydrobatidae* (storm petrels). Signature squarish, well developed. Head much longer than broad, with well developed dorsal carina extending posteriorly at least to level of pulvinus. Ventral carina indistinct to well developed. Antennae usually markedly dimorphic. Head and thorax about equal in length and breadth. Abdomen about twice as long as head plus thorax, straight-sided to spatulate, always widest in region of segment 7. Abdominal segments 9 and 10 almost indistinguishably fused. Sternite 9 and 10 without unusual sclerotizations or chaetotaxy, never divided medially, as in related genera. Genitalia with two variously modified parameres. Male genital opening ventral, sub-terminal.

Genotype: Lipeurus angusticeps Piaget.

Key to the Subgenera of Halipeurus

Dorsal carinae extending to, or almost to level of mandibles, then arcing medially and meeting in mid-line. Female abdomen rounded with slight, rounded medial indentation. Mid-abdominal segments of male with broad buttresses bearing well developed, rounded medial processes; tergites with heavily sclerotized, medially narrowed bands .... Subgenus *Halipeurus*

Dorsal carina extend only to level of pulvinus and end abruptly. Female abdomen distinctly bifid, with deep, triangular indentation, buttresses of segment 11 each terminated with short, very broad seta. Mid-abdominal segments of male with narrow buttresses bearing poorly developed medial processes, usually only at posterior end of buttress. Tergites of male more evenly sclerotized than in *Halipeurus*. Cuticle with obvious scaly appearance. .... Subgenus *Synnautes*

This key is detailed to avoid the equivocation present in the literature today. The two groups are almost generically distinct and easily recognized by anyone familiar with them. The overlap in some characters makes it presently undesirable to maintain these taxonts as separate genera, although additional material may prove that they should be so separated.

Subgenus Halipeurus *Thompson*

Halipeurus Thompson, 1936, Ann. Mag. Nat. Hist. ser. 10, **18**, pp. 40–41. Genotype *Lipeurus angusticeps* Piaget.

Description: Pre- and postmarginal carinae separate to almost joined. Premarginal carina tapered, not obliquely cut distally and interrupting outline of head. Dorsal carinae heavily sclerotized, extending to level of, or almost to mandibles, where they arc medially and meet in mid-line. Buttresses of abdomen relatively broad, those of middle segments particularly with well developed, rounded medial processes. Tergites in male with medially narrowed bands. Eleventh segment of female more or less rounded, with rounded medial indentation, without short stout setae terminating abdomen as in *Synnautes*.

Discussion: Twenty-two species and subspecies of the subgenus are described herein, of which 14 are new. In view of the fact that Kellogg saw many of these new species, and others that were new at the time, and referred them all to *diversus* Kellogg, a complete synonymy would be impossible. Even if Kellogg's host records were used as a basis, such a listing would be completely erroneous inasmuch as he or the people that collected for him were not careful of straggling, as evidenced by his collection. It would be hopeless to properly assign various species unless the actual specimens that he was referring to were at hand. The few that I have, kindly loaned by Dr. Ferris, are mostly stragglers, if the hosts listed on the slides are accurate.

The 22 species and subspecies recognized here may be divided into four major groups of species named as follows: *angusticeps, taxosetus, procellariae,* and *marquesanus* species groups. The first, *angusticeps,* may be readily distinguished by the asymmetry of the terminal segments. It includes three species and one subspecies. There is no way to determine from which of the other groups it evolved, although it seems to be *taxosetus.* In any event, there is no doubt that it is a derivative group. The second, *taxosetus,* is distinguished principally by the shape of the signature. Of the 11 species included within it, 9 are typically parasitic on the birds of the genus *Puffinus.* The third, *procellariae* (three species), and fourth, *marquesanus* (three species), are distinguished from *taxosetus* principally on the basis of the shape of the signature. The relative length of male segment six, near the length of the fifth in *marquesanus* and only about one-half the length of the fifth in *procellariae,* readily separates these two groups. Both *procellariae* and *marquesanus* species groups are typically parasitic on birds of the genus *Pterodroma.*

Key to the Species Groups and Species of Subgenus Halipeurus

This key is primarily based on males, except where females are specifically mentioned. The females by themselves are very difficult to determine, the best technique being to compare them critically with previously determined females of the same size range. When familiar with the lice, one may quickly place females by virtue of certain qualitative aspects that cannot be successfully applied in a key.

1. With obvious asymmetry of part or all of sclerites of terminal segments .... *angusticeps* species group
   Without asymmetrical developments of sclerites of terminal segments 2
2. Signature with lateral expansions and/or without narrow posterior extension .... *taxosetus* species group
   Signature with greatly reduced or no lateral expansions, and with narrow posterior extension 3
3. Female terminal segments typical, not apparently fused into a single, evenly sclerotized unit, medial indentation obvious .... *procellariae* species group
   Female terminal segments apparently fused into a single, more-or-less evenly sclerotized unit, medial indentation greatly reduced or absent; posterior border of segment 11 broad and squared; males without obviously shortened abdominal segment .... *marquesanus* species group

angusticeps *species group*

1. Sternite 9 and 10 only asymmetrical .... *angusticeps* subspp. 2
   Segment 11 markedly asymmetrical 3
2. Sternite 9 and 10 with irregular posterior margin, sharply angled caudad to right; total length greater than 3.6 mm. .... *a. angusticeps*
   Sternite 9 and 10 as above, but less irregular and less sharply angled; total length less than 3.6 mm. .... *a. fosteri*
3. Buttresses of 11th segment only involved in knob-like postanal extension on the right side .... *mirabilis*
   Buttresses of segment 9 and 10 and 11 fused on right side, and form hook-like postanal extension .... *abnormis*

taxosetus *species group*

1. Posterior border of sternite 9 and 10 triangular, heavily sclerotized, with completely atypical setal pattern 9
   Sternite 9 and 10 without excessive modification 2
2. Parameres short, broadened, and widely set apart 10
   Parameres slender, not widely set apart. 3
3. With a row of three closely set setae on each latero-posterior border 7
   Without such a row 4
4. Parameres slender, equal or only slightly sub-equal in length. 5
5. Parameres subspatulate, relatively broad, and differing greatly in length; group II setae somewhat irregular in pattern. .... *placodus*
   Parameres very slender, not varying in width 6
   Parameres slender, but variable in width, from specimen to specimen and point to point along each paramere .... *diversus*
6. Sternite 9 and 10 with rounded, heavily sclerotized corners, presenting superficial 'pincers-like' appearance. .... *forficulatus*
   Sternite not so modified, group 11 setae distinctly caudad on sternite. .... *bulweriae*
7. More than 3.0 mm in length, parasites of *Puffinus.* .... *taxosetus*
   Less than 3.0 mm in length, parasites of *Pelecanoides* .... *falsus* subspp. 8
8. Signature more-or-less *diversus*-type, but irregular. .... *f. falsus*
   Signature distinctive, with large, regularly expanded lateral expansions, narrowing smoothly to small but distinctive medial indentation. .... *f. pacificus*

9. Parameres slender, lightly sclerotized; 11th segment heavily sclerotized but not greatly reduced .... *thompsoni*
Parameres not so slender, heavily sclerotized; aedeagal sac with curious sclerotizations; a large species with 11th segment greatly reduced .... *micariproctus*
10. Sternite 9 and 10 with longitudinally drawn out setal pattern; signature very long, rectangular in shape. .... *attenuatus*
Sternite 9 and 10 with fairly typical setal pattern 11
11. Basal segment of antenna almost bulbous; with slightly irregular setal pattern; aedeagal sac almost as long as parameres; over 3.5 mm in length .... *mundae*
Basal segment of antenna sub-bulbous; with group II setae 5 and 6 distinctly laterad; aedeagal sac with rod-like, obliquely cut sclerotization, less than 3.5 mm in length. ... *turtur*

procellariae *species group*

1. Parameres relatively broad, of medium length, with spatulate tips, subequal and only slightly asymmetrical; with variously modified rod-like sclerotizations within aedeagal sac. 2
Parameres equal in length, symmetrically curved mediad; without sclerotization within aedeagal sac. .... *procellariae*
2. Sternite 9 and 10 rectangular, with typical setal pattern .... *kermadecense*
Sternite 9 and 10 with broadly rounded posterior margin. .... *accentor*

marquesanus *species group*

1. Parameres long and slender 2
Parameres short and relatively broad. .... *intermedius*
2. Sternite 9 and 10 with narrow, rectangular extension overlapping 11th segment. *marquesanus*
Sternite 9 and 10 without such extension, group II setae crowded posteriorly. *postmarquesanus*

Halipeurus (*Halipeurus*) *angusticeps* (Piaget)

Lipeurus angusticeps Piaget, 1880, Les Pediculines, pp. 306–308, pt. 25, fig. 4. *Type-host: Procellaria cinerea.*

Description: A medium-sized species, ± 3.5 mm. Characterized by the irregular, obliquely cut posterior border of sternite 9 and 10 in the male. Signature with deep, triangular medial indentation in female. See descriptions of subspecies for detailed information.

Halipeurus (*Halipeurus*) *angusticeps angusticeps* (Piaget)
(Figs. 3–7, A)

Lipeurus angusticeps Piaget, 1880, Les Pediculines, pp. 306–308, pl. 25, fig. 4. *Type-host: Procellaria cinerea.*
Esthiopterum angusticeps (Piaget). Harrison, 1916, Parasit., **9**, No. 1, p. 130.
Halipeurus angusticeps (Piaget). Thompson, 1936, Ann. Mag. Nat. Hist., ser. 10, **18**, p. 41. Designated as genotype.

Description: Head ratio 2.2. Signature with rounded medial indentation, pointed in female. Basal segment of antenna sub-bulbous. Dorsal carina extends to mandibles, only lightly sclerotized in male. Abdomen ratio 5.8, narrow. Sixth segment as long as fifth. Segments 4, 5 and 6 with well developed paratergal processes, 7, 8 and 9 and 10 without processes. Posterior border of sternite 9 and 10 asymmetrical, cut obliquely downward to right and distinctly irregular. Terminal segments relatively attenuate. Eleventh segment bilobed, relatively unsclerotized, deeply indented. Parameres slender, lightly sclerotized, right paramere shorter and arced medially. Basal apodeme indistinct. Female typical.

Type-host: Unknown. Listed as *Procellaria cinerea* by Piaget, presumably meaning *Adamastor cinereus* (Gmelin).

Measurements: A single male and female, in millimeters:

	Male	*Female*
Total length:	3.84	4.63
Length of head:	0.85	
Width of head:	0.39	
Length of abdomen:	2.38	
Width of abdomen:	0.41	

Material examined: one male, one female, from *Procellaria cinerea* from the Piaget Collection, slide no. 445, BMNH no. 1928–325, kindly loaned by Miss Clay. Male on above slide designated as lectotype. Two male and three female paratypes from same material, all specimens in the British Museum (Natural History).

Discussion: Careful examination of almost 75 museum skins of *Adamastor cinereus* (Gmelin) failed to uncover any specimens of this louse. This seems strange, since the lice of this subgenus are usually reasonably easy to obtain from

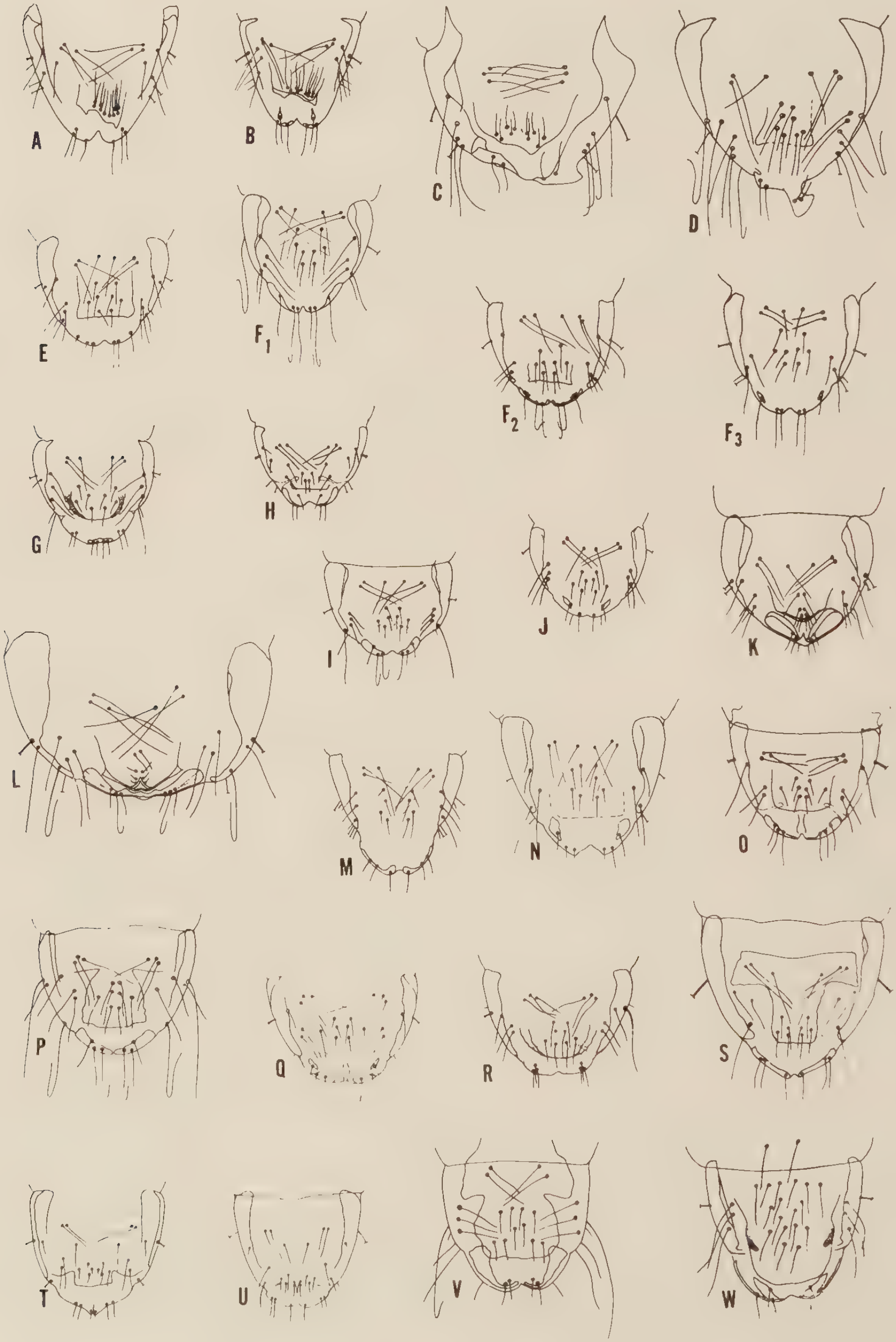

A
B
C
D
E
F_1
F_2
F_3
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

FIGURE 3. Ventral chaetotaxy of male terminal segments.

The diagnostic drawings of figures 3, 4, 5, 6, and 7 are consistently lettered (as listed below) to facilitate their use. They represent specimens from the type-host unless otherwise noted.

A. *Halipeurus (Halipeurus) a. angusticeps* (Piaget)
B. *Halipeurus (Halipeurus) a. fosteri* subsp. nov.
C. *Halipeurus (Halipeurus) abnormis* (Piaget)
D. *Halipeurus (Halipeurus) mirabilis* Thompson
E. *Halipeurus (Halipeurus) placodus* sp nov.
F. *Halipeurus (Halipeurus) diversus* (Kellogg)
  1, specimens from type host *Puffinus griseus* (Gmelin)
  2, specimens from *Puffinus l. boydi* Mathews
  3, specimens from *Puffinus p. yelkouan* (Acerbi)
G. *Halipeurus (Halipeurus) forficulatus* sp. nov.
H. *Halipeurus (Halipeurus) bulweriae* sp. nov.
I. *Halipeurus (Halipeurus) taxosetus* sp. nov.
J. *Halipeurus (Halipeurus) falsus* Eichler
  1, specimens from *Pelecanoides garnotti* (Lesson), the type host
  2, specimens from *Pelecanoides urinatrix* (Gmelin), type host of *H. f. pacificus* subsp. nov.
K. *Halipeurus (Halipeurus) thompsoni* sp. nov.
L. *Halipeurus (Halipeurus) micariproctus* sp. nov.
M. *Halipeurus (Halipeurus) attenuatus* sp. nov.
N. *Halipeurus (Halipeurus) mundae* sp. nov.
O. *Halipeurus (Halipeurus) turtur* sp. nov.
P. *Halipeurus (Halipeurus) procellariae* (Fabricius)
Q. *Halipeurus (Halipeurus) kermadecense* (Johnston and Harrison)
R. *Halipeurus (Halipeurus) accentor* sp. nov.
S. *Halipeurus (Halipeurus) intermedius* nom. nov.
T. *Halipeurus (Halipeurus) marquesanus* (Ferris)
U. *Halipeurus (Halipeurus) postmarquesanus* sp. nov.
V. *Halipeurus (Synnautes) pelagicus* (Denny)
W. *Halipeurus (Synnautes) nesofregettae* sp. nov.

skins. None of the other species of birds of the subfamily Puffininae examined carried specimens of *angusticeps.*

This species of louse is very closely related to that parasitizing *Puffinus leucomelas,* and, in view of the opinion that *leucomelas* is closely, perhaps subspecifically related to *Puffinus kuhlii, H. a. angusticeps* may parasitize a local population of *kuhlii.* However, all of the skins of the various subspecies of *kuhlii* examined carried specimens of *H. abnormis* (Piaget) only.

Halipeurus (Halipeurus) a. fosteri subsp. nov.

(Figs. 3–7, B)

Description: Smaller, but essentially as *H. a. angusticeps,* differing as follows: Head ratio 2.1. Dorsal carina typical, except only lightly sclerotized near level of mandibles. Abdomen ratio 6.0. Sternite 9 and 10 with irregular posterior margin, obliquely cut to right, heavily sclerotized, but not sloped as sharply and less irregular. Right paramere only slightly curved medially.

Measurements: 9 males, 5 females, averages and ranges, in millimeters:

	Males	*Females*
Total length	3.53 (3.38 to 3.54)	4.38 (4.31 to 4.46)
Length of head	0.75 (0.73 to 0.78)	
Width of head	0.36 (0.36 to 0.37)	
Length of abdomen	2.24 (2.16 to 2.32)	
Width of abdomen	0.37 (0.34 to 0.41)	

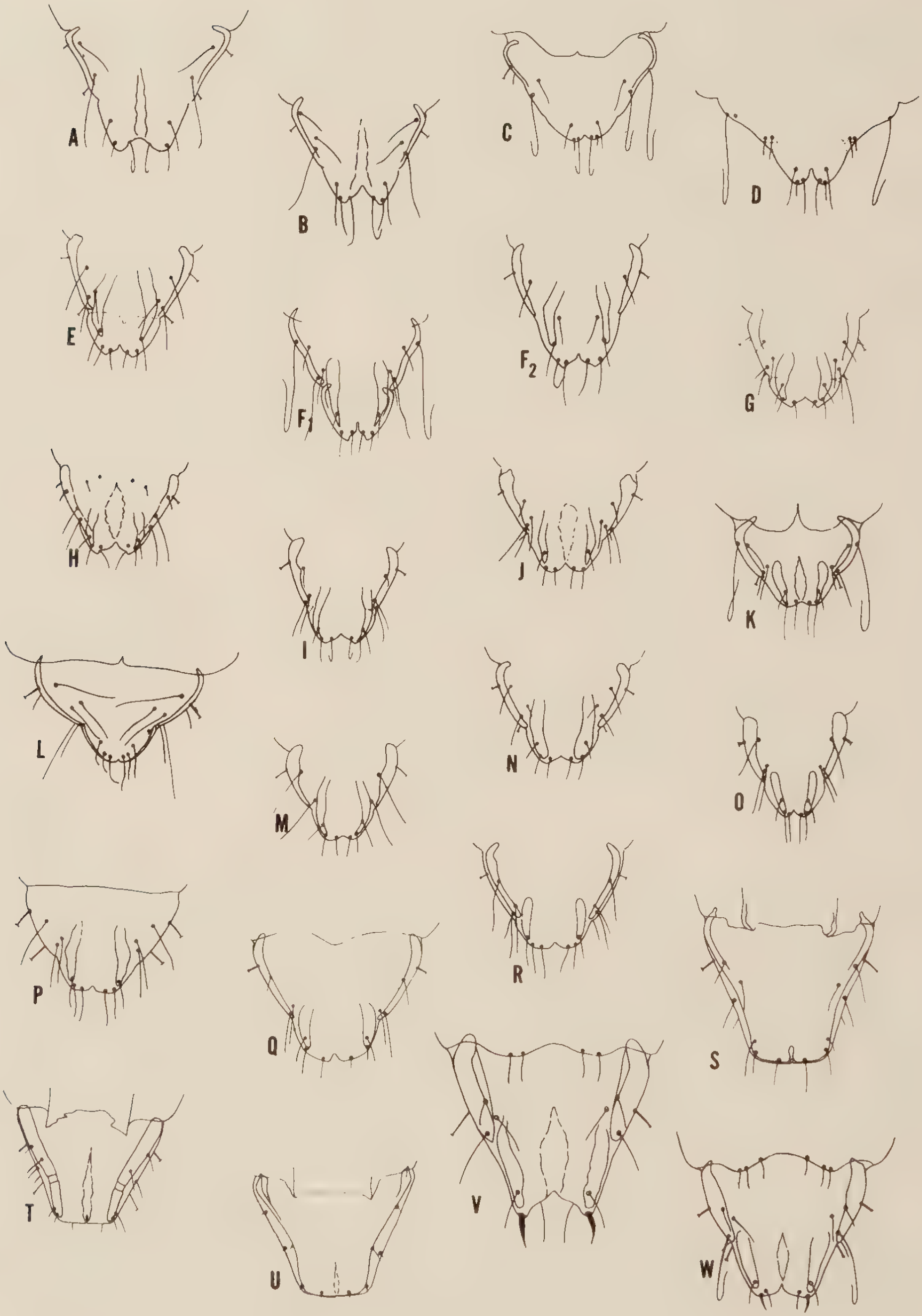

A
B
C
D
E
F1
F2
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

FIGURE 4. Ventral chaetotaxy of female terminal segments. (Labeling same as for figure 3.)

Type-host: *Puffinus leucomelas* (Temminck).

Material Examined: All from the type-host as follows: Holotype male, allotype female, 1 male and 8 female paratypes, from MCZ skin no. 131515, collected from China Sea between Shanghai and Foochow (RLE); 1 male, 1 female, paratypes, from 3° 10′ S, 155° E, no further data (AMNH) slide); 4 male, 6 female paratypes, from New Guinea, no further data (GBT); 3 male, 6 female paratypes from AMNH skin no. 220603, collected at 3° 10′ S, 155° E (RLE).

Halipeurus (*Halipeurus*) *abnormis* (Piaget)

(Figs. 3–7, C)

Lipeurus abnormis Piaget, 1885, Les Pediculines, sup., pp. 65–66, pl. 7, fig. 2. *Type-host:* *Puffinus major.*

Esthiopterum abnorme (Piaget). Harrison, 1916, Parasit., **9**, No. 1, p. 129.

Halipeurus abnormis (Piaget). Thompson, 1938, Ann. Mag. Nat. Hist., ser, 11, **2**, p. 482.

Description: A large species, head ratio 1.8, signature squarish; rounded posterior indentation, usually shallow and indistinct. Basal segment of antenna bulbous, second enlarged, distal two segments relatively small; first three segments more or less coalesced into a single tapered unit. Abdomen ratio 4.8, relatively broad, spatulate. Paratergites as in *H. angusticeps* and *fosteri*. Segment 6 about three-fourths as long as 5th. Terminal segments assymmetrical, heavily sclerotized. Paratergites 9, 10, and 11 fused and terminally arced laterad on right, 11th separate on left. Sternite 9 and 10 broad, heavily sclerotized and slightly asymmetrical, pattern typical, slightly distorted. Genitalia also heavily sclerotized, with parameres broadened out basically as in *H. a. fosteri*. Many irregular sclerotizations within or upon aedeagal sac. Female with distinct ventral clypeal bands. Terminal segments short, weakly sclerotized.

Measurements: 7 males, 10 females, averages and ranges in millimeters, from *Puffinus kuhlii edwardsi:*

	Males	*Females*
Total length	4.36 (4.15 to 4.54)	4.97 (4.76 to 5.38)
Length of head	0.89 (0.85 to 0.92)	
Width of head	0.49 (0.46 to 0.51)	
Length of abdomen	2.77 (2.62 to 2.93)	
Width of abdomen	0.58 (0.54 to 0.65)	

Type-host: *Puffinus gravis* (O'Reilly)

Material Examined: From various subspecies of *Kuhlii* and the type-host as follows:

Puffinus k. kuhlii (Scopoli): 1 male, 1 female, from MCZ skin no. 47230, South Spain (RLE): 3 males, 8 females, from Greece and Spain, (GBT).

Puffinus k. borealis Cory: 8 males, 16 females, from MCZ skin no. 135290, Azores, (RLE).

Puffinus k. edwardsii (Oustalet): 7 males, 16 females from MCZ skin no. 94293, (RLE).

Puffinus k. flavirostris (Gould): 1 male, Cape Seas, (GBT).

Puffinus gravis (O'Reilly): Male (here designated as lectotype) in the Piaget Collection, BMNH slide no. 454. Four male and two female paratypes.

Discussion: This large species is obviously related to *H. a. fosteri* and *H. angusticeps*. It differs, however, in that it has an unusual asymmetrical development of its terminal segment. The parameres are basically the same shape as in the above mentioned species, but are broader, more heavily sclerotized, and overshadowed by the sclerotizations in the aedeagal sac.

Puffinus gravis carries two species of *Halipeurus; abnormis* and *micariproctus* sp. nov. It is unusual for a host to be parasitized by two so closely related species. There seems little doubt, however, that this situation is a true one. It would be interesting to know if any one individual bird has thriving populations of both of these *Halipeurus* species.

Halipeurus (*Halipeurus*) *mirabilis* Thompson

(Figs. 3–7, D)

Halipeurus mirabilis Thompson, 1940, Ann. Mag. Nat. Hist., ser. 11, **5**, pp. 499–502, text figs. 1–5, pl. 10, figs. 1, 2.

Type-host: *Puffinus pacificus chlororhynchus* Lesson.

Description: Head ratio 2.0. Signature with broadly rounded posterior indentation. Basal

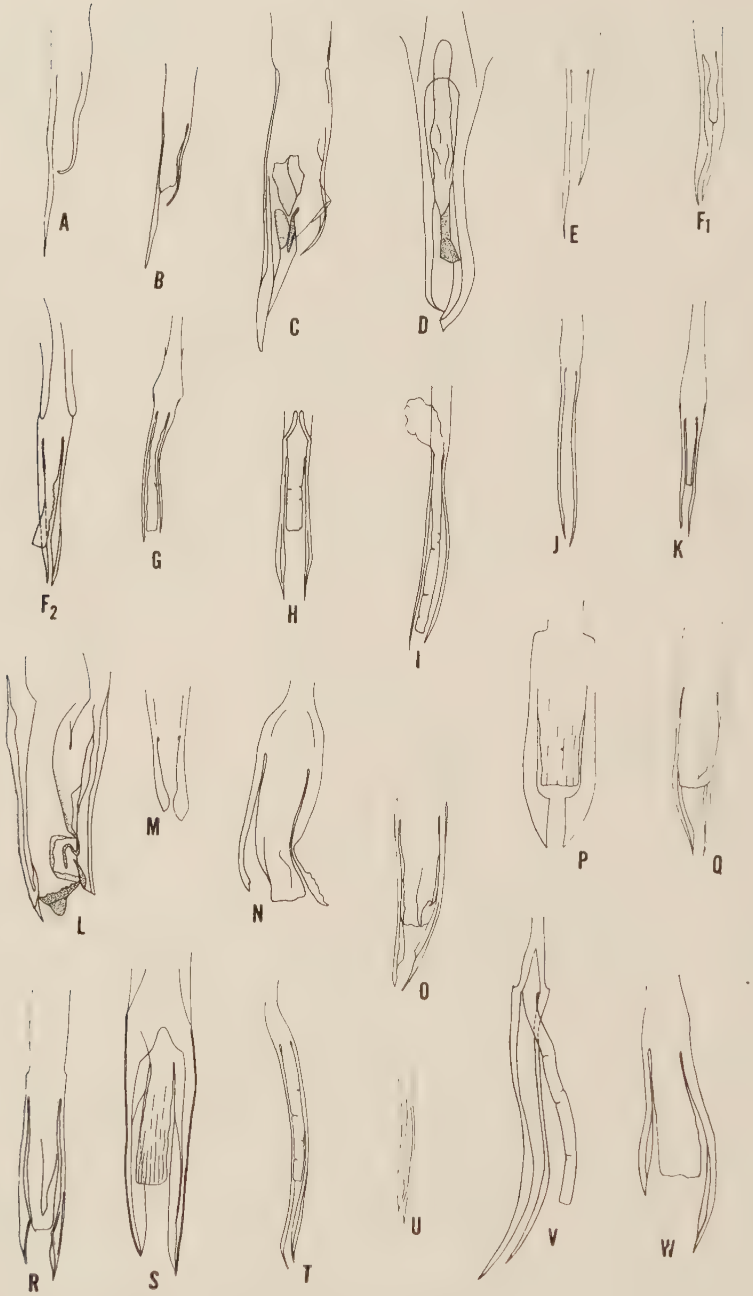


FIGURE 5. Male genitalia. (Labeling same as for figure 3.)

segment of antenna bulbous, second segment only slightly enlarged. Abdomen ratio 5.1, subspatulate. Sixth segment slightly longer than fifth. Paratergites as in *H. angusticeps*. Eleventh segment has heavily sclerotized asymmetrical developments, with knob-like extension on right side. Sternite 9 and 10 narrow, sclerotized, with typical but slightly distorted setal pattern. Genitalia heavily screlotized, subequal, parameres broad, curved mediad distally.

Measurements: 5 males and 6 females, averages and ranges in millimeters:

	Males	*Females*
Total length	4.50 (4.38 to 4.62)	4.64 (4.62 to 4.70)
Length of head	0.83 (0.82 to 0.85)	
Width of head	0.43 (0.41 to 0.44)	
Length of abdomen	3.04 (2.92 to 3.08)	
Width of abdomen	0.59 (0.58 to 0.64)	

Type-host: Puffinus pacificus chlororhynchus Lesson.

Material examined: 1 male, 2 female paratypes from the type-host, kindly loaned by Mr. G. B. Thompson, the original describer. Other material as follows:

Puffinus pacificus chlororhynchus Lesson: 4 males, 4 females, from AMNH skin collected near Banks Island (RLE).

Puffinus pacificus pacificus (Gmelin): 4 males, 8 females, collected near Sunday, Kermadec Islands (RLE).

Puffinus pacificus cuneatus Salvin: 2 males, 5 females from MCZ skin no. 239641, Oahu, Hawaiian Islands (RLE).

Discussion: The relationship of other species to this one is obscure, although it seems to be related to those previously discussed. It is easily distinguished by the asymmetrical developments of the 11th segment.

Halipeurus (Halipeurus) placodus sp. nov.
(Figs. 3–7, E)

Description: Like *diversus,* from many hosts and variable. Head ratio 2.1. Signature with shallow medial indentation. Abdomen ratio 5.8, broader relatively than *diversus,* slightly broadened posteriorly. Buttresses with well developed medial processes. Sixth segment less than one-half as long as fifth. Terminal segments similar to *diversus* with less sclerotization of 11th and considerably more of sternite 9 and 10. Setal pattern of sternite 9 and 10 typical, with almost no variation. Parameres of genitalia distinctly subequal, broadened distally with pointed tips. Basal apodeme broad, moderately sclerotized.

Type-host: Puffinus assimilis tunneyi Mathews.

Measurements: Averages and ranges in millimeters of 6 males, 6 females, from type-host:

	Males	*Females*
Total length	3.37 (3.31 to 3.39)	4.08 (4.00 to 4.15)
Length of head	0.69 (0.68 to 0.72)	
Width of head	0.33 (0.32 to 0.34)	
Length of abdomen	2.05 (2.00 to 2.16)	
Width of abdomen	0.35 (0.34 to 0.37)	

Material examined: From the type-host; holotype male, allotype female, 3 male, 5 female paratypes, from MCZ skin no. 166366, West Wallaby Island, Australia, (RLE). From other hosts as follows:

Puffinus assimilis assimilis Gould: 4 males, 7 females from MCZ skin no. 236975, collected near the Herald Islands, South Pacific, (RLE).

Puffinus assimilis kermadecensis Murphy: 10 male, 11 female paratypes collected near Kermadec Islands, (RLE).

Puffinus l'herminieri nugax Mathews: 2 male, 4 female paratypes, from AMNH skin no. 216890, collected near New Hebrides, (RLE).

Puffinus auricularis Townsend: 3 males, stragglers?, MCZ skin from Charion Islands, (RLE).

Discussion: The apparently anomalous distribution of this louse on various host species illustrates the ever-present danger of leaning too heavily on parasitic distribution as a clue to host relationship. This is especially true at the species level of the louse. This species, *placodus,* may be found on three subspecies of *Puffinus assimilis* as well as one subspecies of *P. l'herminieri* and perhaps lends some slight support to Murphy's (1927) division of *assimilis* into two species, *assimilis* and *l'herminieri.*

This species can be readily separated from *diversus* which it superficially resembles by the unequal parameres, the typical setal pattern, the shorter 6th abdominal segment, the more obviously sclerotized sternite 9 and 10 with its distinct posterior margin, and the narrower abdomen. The females may be separated by size differences only.

Halipeurus (*Halipeurus*) *diversus* (Kellogg)
(Figs. 3–7, F)

Lipeurus diversus Kellogg, 1896, New Mallophaga 1, pp. 123–124, pl. 8, figs. 3, 4. *Type-host: Puffinus opisthomelas* Coues.

Lipeurus limitatus Kellogg, as above, pl. 8, figs. 5, 6. Immature of *diversus*. *Type-host: Puffinus griseus* (Gmelin).

Esthiopterum diversum (Kellogg). Harrison, 1916, Parasit., **9**, No. 1, p. 133.

Esthiopterum constrictiventre Pessoa and Guimaraes, 1935, Ann. Fac. Med., Sao Paulo, fasc. 3, **11**, pp. 5–6, figs. 6, 7. *Type-host: Aestrelata macroptera* Smith.

Halipeurus diversus (Kellogg). Thompson, 1938, Ann. Mag. Nat. Hist., ser. 11, **2**, p. 485.

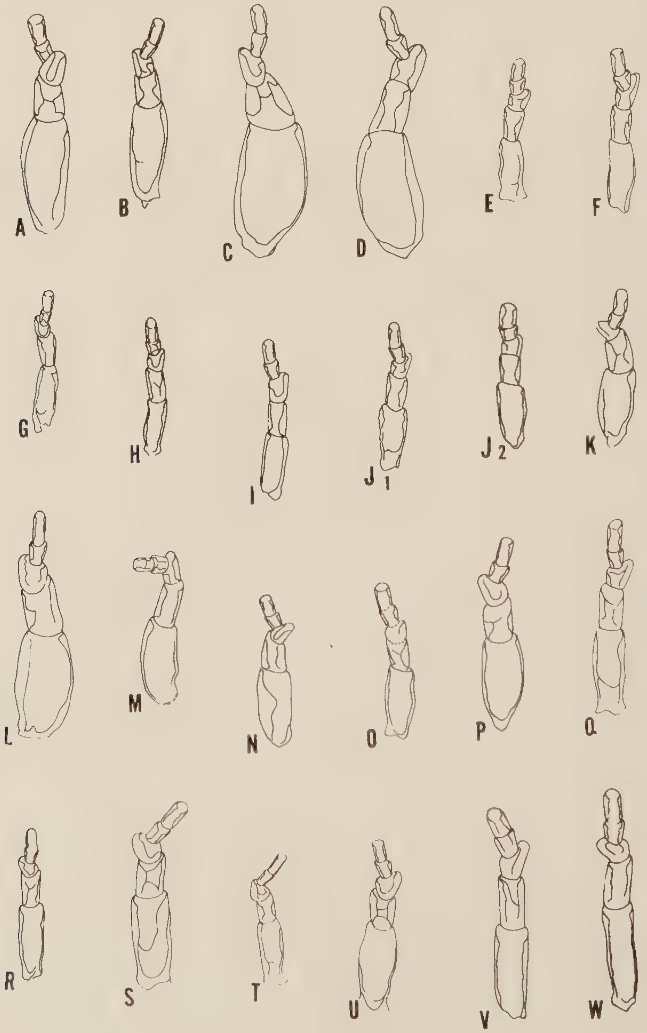


FIGURE 6. Male antennae. (Labeling sames as for figure 3.)

Description: Head ratio 2.0. Signature with well-developed lateral extensions and shallow medial indentation. Basal segment cylindric. Abdomen ratio 6.1, almost straight-sided. Sixth segment one-half or more longer than 5th. All paratergal buttresses with medial processes. Paratergite 9 and 10 relatively long, slender, tapering. Setal pattern of sternite 9 and 10 almost typical, except that setae nos. 1 and (especially) 2 vary in position anteriorly. Seta no. 2 usually displaced further anteriorly, often paralleled by nos. 5 and 6, (specimens from *Puffinus puffinus* subspp. vary the most). Sternite 9 and 10 sufficiently sclerotized so that posterior margin is especially distinct. Parameres long, relatively broad, barely subequal.

Measurements: 10 males and 10 females from *Puffinus griseus,* averages and ranges as follows:

	Males	*Females*
Total length	3.69 (3.53 to 3.84)	4.36 (4.15 to 4.53)
Length of head	0.76 (0.73 to 0.78)	
Width of head	0.38 (0.36 to 0.39)	
Length of abdomen	2.27 (2.15 to 2.31)	
Width of abdomen	0.37 (0.34 to 0.39)	

Type-host: Puffinus griseus (Gmelin), see discussion.

Material examined: Kellogg types, 2 males, 1 female, host labeled as *Puffinus opisthomelas,* Pacific Grove, Calif., slide no. 140b, and types of *Lipeurus limitatus,* similarly labeled, slide no. 140c, kindly loaned me by Dr. G. E. Ferris, Stanford University. Other material as follows:

Puffinus griseus (Gmelin): 13 males, 25 females, off Moki Hinau, New Zealand (RLE); 1 male, 1 female, Depoe Bay, Oregon, H. S. Fuller, collector.

Puffinus tenuirostris (Temminck): 11 males, 10 females, from MCZ skin no. 318119, collected near Kodiak Island, Alaska (RLE); 3 males, 1 female from Bass Straits, New Zealand (RLE).

Puffinus puffinus puffinus (Brunnich): 1 male, 4 females from Mar del Plata, Argentina, (RLE); 15 males, 13 females, from British Isles, (Meinertzhagen); 3 males, 7 females, from British Isles, (GBT).

Puffinus puffinus yelkouan (Acerbi): 4 females, from MCZ skin, collected at Majorca, (RLE).

Puffinus puffinus mauretanicus Lowe: 3 females, from MCZ skin, British Isles, (RLE); 1 female, Balearic Islands, (Meinertzhagen).

Puffinus l'herminieri boydi Mathews: 4 males, 10 females, from AMNH skin no. 527894, Robbos Group, Cape Verde Islands, (RLE); 1 male and 3 females, Cape Verde Island (Meinertzhagen).

Pterodroma macroptera macroptera Smith: 1 male, 1 female compared with type of *Esthiopterum constrictiventre,* collected at Guaruja, S. P., Brazil, kindly sent to me by Dr. Lindolfo Guimaraes. There are almost certainly stragglers, *Halipeurus procellariae* (Fab.) usually parasitizing this host.

Discussion: Kellogg's types of *diversus* are almost certainly stragglers or the result of a mix-up during processing. The type-host, *Puffinus griseus,* was chosen because it harbors this species of louse commonly and because Kellogg assigns the type-host of the nymph, which he described as *Lipeurus limitatus,* as *Puffinus griseus* in the text. This, despite the fact that the type label gives *Puffinus opisthomelas* as the host.

This species ranges almost around the world on its various hosts. Although differences can be seen in populations from each of these species, the range of differences in each precludes the possibility that they have subspeciated to the extent that each host bears lice that have a consistent morphological identity. The lice from *Puffinus l. boydi* (figs. 3 and 5, F-2) range from typical *diversus* to a condition in which sternite 9 and 10 is obviously more heavily sclerotized, while those from *Puffinus p. yelkouan* (figs. 3, 4 and 7, F-3) range from typical *diversus* to specimens having only a minute amount of sclerotization in the terminal segments.. This unusual amount of variation from collection to collection within each host species strongly suggests that changes are presently taking place.

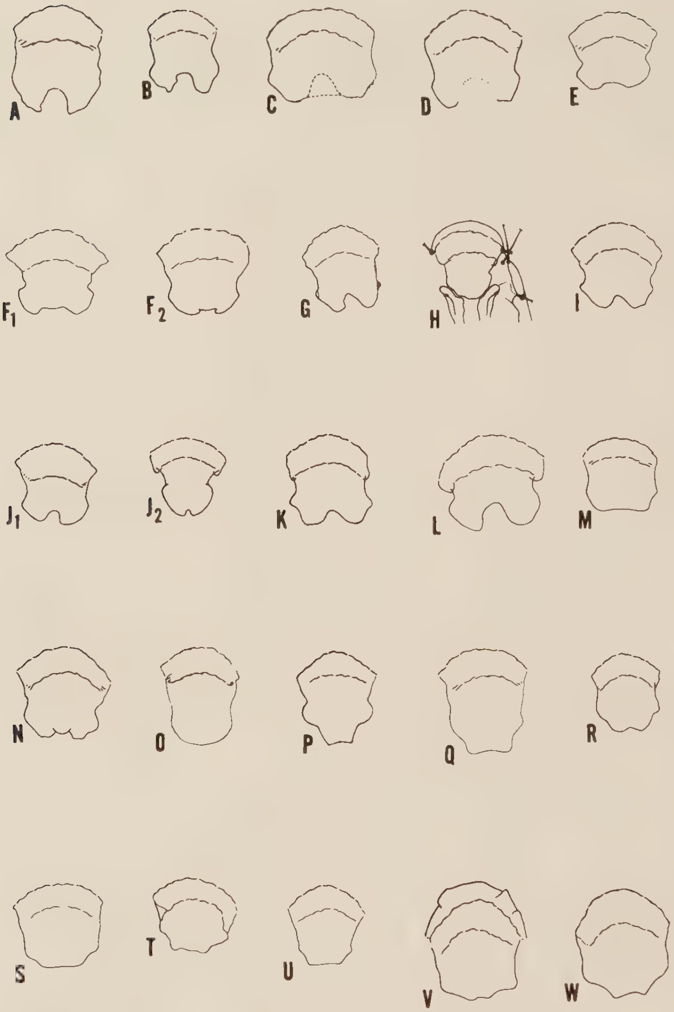


FIGURE 7. Male signatures. (Labeling same as for figure 3.)

Halipeurus (*Halipeurus*) *forficulatus* sp. nov.
(Figs. 3–7, G)

Description: Head ratio 2.3, very narrow. Signature elongated, relatively straight-sided; relatively deep, irregularly rounded medial indentation. Basal segment of antenna cylindric. Abdomen ratio 6.8, narrow and straight-sided. Segments 2 to 8 with well developed medial processes on buttresses. Sixth segment slightly less than one-half as long as 5th. Eleventh segment rounded, no medial division, with distinct apical sclerotizations. Sternite 9 and 10 heavily sclerotized, broadly rounded posteriorly, with lateral margins built up and irregularly scalloped, presenting the appearance of a pair of pincers. Parameres long and slender, barely subequal, with aedeagal sac almost as long as shortest paramere.

Measurements: 10 males, 10 females from all hosts, averages and ranges in millimeters:

	Males	*Females*
Total length	3.36 (3.15 to 3.54)	3.94 (3.85 to 4.00)
Length of head	0.69 (0.65 to 0.71)	

Width of head	0.30 (0.28 to 0.31)
Length of abdomen	2.11 (2.00 to 2.24)
Width of abdomen	0.31 (0.27 to 0.34)

Type-host: *Puffinus l'herminieri polynesiae* Murphy.

Material examined: From the type-host: Holotype male and allotype female, 4 male and 5 female paratypes, from MCZ skin no. 191742, collected near Manoui, (RLE); 3 male, 2 female paratypes, Marquesas Islands, (BMNH).

Puffinus l'herminieri dichrous Finsch and Hartlaub: 3 male, 5 female paratypes, from AMNH skin, collected near Palau, Caroline Islands, (RLE).

Puffinus heinrothi Reichenow: 3 males from AMNH skin no. 230280, New Britain, (RLE). Stragglers?

Discussion: A distinctive louse; the modification of sternite 9 and 10 and the elongate signature serve to separate it from all other species. If the record from *Puffinus heinrothi* is valid, the list of hosts again suggests that geography, with the aid of an unknown agent, sometimes has more to do with the distribution of these lice than the relationships of the hosts.

Halipeurus (*Halipeurus*) *bulweriae* sp. nov.
(Figs. 3–7, H)

Description: A small species, superficially like *Synnautes.* Head ratio 2.4, very narrow. Signature elongated, rounded posterially. With obvious hiatus between postmarginal carina and dorsal carina. Premarginal and postmarginal carinae are virtually fused. Abdomen ratio 6.8, narrow and straight-sided. Buttresses very narrow, with knob-like medial processes developed only on posterior ends. Segment 6 about one-half the length of 5. Parameres long, slender, only slightly sub-equal, curved mediad slightly at tips. Aedeagal sac almost as long as parameres.

Measurements: 5 males, 5 females from the type-host, averages and ranges in millimeters.

	Males	*Females*
Total length	3.30 (3.15 to 3.46)	3.78 (3.70 to 3.85)
Length of head	0.69 (0.67 to 0.72)	
Width of head	0.29 (0.27 to 0.31)	
Length of abdomen	2.13 (2.07 to 2.22)	
Width of abdomen	0.31	

Type-host: *Bulweria bulweria* (Jardine and Selby).

Material examined: Holotype male, allotype female, 2 males, 3 female paratypes, from type host, from MCZ skin collected near Canary Islands, (RLE); 1 male, 2 female paratypes, no data, (GBT); 1 male, 2 female paratypes, Canary and Madeira Islands, (Meinertzhagen).

Halipeurus (*Halipeurus*) *taxosetus* sp. nov.
(Figs. 3–7, I)

Description: Similar to *H. diversus.* Head ratio 2.0. Signature variable, usually slightly elongate compared with *H. diversus,* with pronounced lateral extensions and rounded medial indentation. Basal segment of antenna cylindric. Abdomen ratio 6.2. Buttresses with well developed medial processes. Segment 6 slightly more than one-half as long as 5. Eleventh segment with lightly sclerotized buttress, rounded, with only a slight medial indentation. Sternite 9 and 10 with typical setal pattern, two rows of three closely set, stouter setae laterad of group II. Parameres long and slender, slightly subequal. Female typical.

Measurements: 10 males and 10 females from *Puffinus nativitatis,* averages and ranges in millimeters.

	Males	*Females*
Total length	3.39 (3.31 to 3.54)	3.93 (3.85 to 4.00)
Length of head	0.70 (0.68 to 0.73)	
Width of head	0.34 (0.33 to 0.35)	
Length of abdomen	2.10 (2.00 to 2.16)	
Width of abdomen	0.34 (0.32 to 0.35)	

Type-host: *Puffinus nativitatis* Streets.

Material examined: From the type-host, holotype male, allotype female, 20 male, 27 female paratypes, from Dukie Island, and Christmas Island, collected by R. H. Beck (AMNH); 8 male, 12 female paratypes, from MCZ skins, Laysan Island (RLE).

Puffinus gavia (Forster) (= *P. reinholdi* Mathews): 8 males, 5 females, collected by R. H. Beck at 44 S, 173 W. (AMNH).

Puffinus opisthomelas Coues: 8 males, 8 females, from MCZ skin, Monterey and Santa Monica, Calif., (RLE).

Puffinus l'herminieri l'herminieri Lesson: 9 males, 14 females, from MCZ skin no. 90670, Ginger Island, Bahamas, (RLE), 1 male, 1 female, from the Bahamas, (GBT).

Two males, 2 females, Krusenstern Island, (GBT). Other material as follows:

Puffinus l'herminieri bannermani Mathews and Iredale: 2 males, 2 females, from MCZ skin no. 82908, near North Iwo Jima, Bonin Islands, (RLE).

Puffinus l'herminieri bailloni (Bonaparte): 1 male, from AMNH skin collected at Prustin Island, Seychelles, (RLE).

Puffinus assimilis baroli (Bonaparte): 2 males, 4 females, from MCZ skin no. 42011, collected near Porto Santo, Madeira Islands, (RLE).

Discussion: Closely related to *Halipeurus falsus* Eichler and possibly conspecific with it. I believe that these two species should be left as is, pending further material from *Pelecanoides* and knowledge of these lice in general. It differs in the shape of the parameres, size generally and in length of the parameres. The usually conservative females can be separated instantly on the basis of the shape of the signature. With the above noted exception, it can be instantly separated from all other species on the basis of the two rows of three closely set setae on sternite 9 and 10. The sclerotization of the 11th segment links this species with *Halipeurus thompsoni.*

Halipeurus (*Halipeurus*) *falsus* Eichler

Halipeurus falsus Eichler, 1949, Rev. Brasil. Biol. **9**, No. 3, pp. 338, text figs. 2, 3. Type-host: *Pelecanoides garnotti* (Lesson).

Description: Essentially as *diversus,* but much smaller, less than 2.7 mm in length. Signature with broad but variable lateral expansions. For detailed information, see descriptions of subspecies below.

Type-host: *Pelecanoides garnotti* (Lesson).

Discussion: Eichler's description, beyond the fact that a type-host is designated, is virtually useless, and is based on a single female! It is presumed here that the specimens collected from *Pelecanoides garnotti* are the same as his.

Halipeurus (*Halipeurus*) *falsus falsus* Eichler
(Figs. 3–7, J-1)

Halipeurus falsus Eichler, 1949, Rev. Brasil. Biol. **9**, No. 3, pp. 338, text figs. 2, 3. Type-host: *Pelecanoides garnotti* (Lesson).

Description: Much smaller, but similar generally to *H. taxosetus* sp. nov. Head ratio 2.0. Signature variable, but generally distinctive in that lateral expansions are large and irregular in outline. Medial indentation variable, usually narrow and straight sided. Abdomen ratio 6.0. Buttresses with well-developed medial processes. Buttress 9 and 10 only lightly sclerotized. Sixth segment only slightly more than one-half as long as the 5th. Setal pattern as in *H. taxosetus,* with small variations, especially in two rows of three closely set setae laterad on sternite 9 and 10. Female with signature like that of male.

Measurements: 10 males, 10 females, from the type-host; averages and ranges in millimeters.

	Males	*Females*
Total length	2.90 (2.70 to 2.93)	3.45 (3.32 to 3.70)
Length of head	0.63 (0.60 to 0.66)	
Width of head	0.32 (0.31 to 0.34)	
Length of abdomen	1.80 (1.69 to 1.85)	
Width of abdomen	0.30 (0.27 to 0.32)	

Type-host: *Pelecanoides garnotti* (Lesson).

Material examined: All from the type-host as follows: Allotype male, 5 other males and 2 females, from MCZ skin no. 82890, Valparaiso, Chile (RLE); 1 male, 2 females, Valparaiso, Chile, (GBT); 13 males, 13 females, Ancon, Peru, (AMNH).

Halipeurus (*Halipeurus*) *falsus pacificus* subsp. nov.

(Figs. 3–7, J-2)

Description: Head ratio 1.9. Signature distinctly modified, with hyaline, 'ear-like' processes laterad of lined area, and broadly expanded, lateral expansions which smoothly curve mediad to a small, rounded medial indentation. Basal segment of antenna relatively short and sub-bulbous; distal two segments barely angled. Abdomen ratio 5.2. Sixth segment two-thirds as long as 5th. Female with distinctive signature.

Measurements: 6 males and 16 females from all hosts; averages and ranges in millimeters.

	Males	*Females*
Total length	2.74 (2.62 to 2.77)	3.16 (3.00 to 3.38)
Length of head	0.61 (0.61)	
Width of head	0.32 (0.31 to 0.34)	
Length of abdomen	1.68 (1.61 to 1.69)	
Width of abdomen	0.32 (0.29 to 0.33)	

Type-host: *Pelecanoides urinatrix* (Gmelin). See discussion.

Material examined: On various hosts as follows:

Pelecanoides urinatrix (Gmelin): Holotype male, allotype female, paratype male, from AMNH skin no. 528725, New Zealand (RLE). 1 damaged male, 1 female from New Zealand (GBT). 1 male, 1 female, paratypes, New Zealand (RLE).

Pelecanoides magellani (Mathews): 2 male, 10 female paratypes, from southern coast of Chile, (AMNH).

Pelecanoides exsul Salvin: 1 male, 3 females, from AMNH skin no. 211800, collected near Channel Island, New Zealand, (RLE). 1 male and 1 female, from New Zealand, (GBT).

Halipeurus (*Halipeurus*) *thompsoni* sp. nov.

(Figs. 3–7, K)

Description: Head ratio 2.1. Signature variable in length, with deep, irregularly rounded median indentation. Small 'ear-like' hyaline extensions of lateral margin anteriorly. Basal segment of antenna relatively short, essentially sub-bulbous; 2d segment enlarged, as broad as basal segment. Abdomen ratio 5.1. Buttresses with medial processes developed. Segment 6 about two-thirds the length of 5. Buttress 9 and 10 relatively long and narrow, curving mediad distally. Segment 11 with moderately sclerotized tergite and buttress, not divided apically. Sternite 9 and 10 with heavily sclerotized posterior margin, overlapping 11th segment. Setal pattern modified, group II setae in two parallel rows. Parameres only lightly sclerotized, slender, subequal. Basal apodeme broad, indistinct. Terminal segments of female reduced slightly. Signature like that of *taxosetus*.

Measurements: 8 males and 4 females from type-host; averages and ranges in millimeters.

	Males	*Females*
Total length	3.46 (3.23 to 3.54)	4.02 (3.93 to 4.08)
Length of head	0.78 (0.73 to 0.80)	
Width of head	0.37 (0.34 to 0.37)	
Length of abdomen	2.12 (2.00 to 2.15)	
Width of abdomen	0.41 (0.37 to 0.44)	

Type-host: *Puffinus bulleri* Salvin.

Material examined: From the type-host, holotype male, allotype female, 24 male, 21 female paratypes, collected at various places along the coast of Chile by R. H. Beck, (AMNH).

Discussion: This species is named for Mr. Gordon B. Thompson, who has kindly supplied me with considerable material.

This species links *Halipeurus taxosetus* with *H. micariproctus* sp. nov. a larger species with extreme reduction and sclerotization of the 11th segment.

It is easily separated from all other species by the sclerotized modifications of the terminal segments.

Halipeurus (*Halipeurus*) *micariproctus* sp. nov.
(Figs. 3–7, L)

Description: Large. Head ratio 1.85, broad. Signature with pronounced hyaline 'ear-like' processes anteriorly; median indentation broadly rounded. Posterior margin of lateral expansion occasionally irregularly fused to dorsal carina. Basal segment of antenna bulbous, 2nd segment enlarged. Abdomen ratio 4.6, spatulate. Medial processes broadly rounded where present, buttresses 7 and 8 almost straight medially. Segment 6 only slightly shorter than 5. Distal portion of buttress 9 and 10 strongly curved mediad. 11th segment greatly reduced, although heavily and distinctively sclerotized. Sternite 9 and 10 essentially as in *H. thompsoni,* although more heavily sclerotized and extending almost to apex of abdomen. Genitalia heavily sclerotized, with subequal parameres and a caplike sclerotization distad on the aedeagal sac. Basal apodeme indistinct. Female not larger than male, an unusual condition, and with greatly reduced terminal segments; signature without 'ears'.

Measurements: 8 males, 14 females from the type-host; averages and ranges in millimeters:

	Males	*Females*
Total length	4.98 (4.76 to 5.15)	4.90 (4.76 to 5.15)
Length of head	0.91 (0.88 to 0.95)	
Width of head	0.49 (0.48 to 0.51)	
Length of abdomen	3.32 (3.15 to 3.38)	
Width of abdomen	0.72 (0.65 to 0.78)	

Type-host: *Puffinus carneipes* Gould.

Material examined: From the type-host, holotype male, allotype female, 6 male and 20 female paratypes, from various places around New Zealand (RLE). From other hosts as follows:

Puffinus creatopus Coues: 6 males, 18 females, from MCZ skins collected at Monterey Bay, Calif., and along Chilean coast, (RLE).

Puffinus gravis (O'Reilly): 12 males and 15 females from AMNH skins, collected along the Argentine coast (RLE); 1 male and 2 females from the South Atlantic, (GBT).

Discussion: This species may be readily separated from all others on the basis of its modified terminal segments. It is most unusual in that the females are not markedly larger than the males.

Halipeurus (*Halipeurus*) *attenuatus* sp. nov.
(Figs. 3–7, M)

Description: Head ratio 1.9, broadest above antenna. Signature more-or-less straight-sided, elongated, without a median indentation. Ventral carina indistinct. Basal segment of antenna subcylindric. Abdomen ratio 6.8. All buttresses with only slightly developed medial processes. Segment 6 only one-third the length of 5. Terminal segments elongated, 11th segment with obvious buttress, broadened distally. Sternite 9 and 10 with drawn-out setal pattern. Parameres short, straight and spatulate, subequal. Aedeagal sac almost as long as longest paramere. Female signature squared, as in male; with relatively elongate terminal segment.

Measurements: 7 males, 6 females from the type-host, averages and ranges in millimeters:

	Males	*Females*
Total length	3.52 (3.38 to 3.54)	3.87 (3.85 to 4.00)
Length of head	0.70 (0.68 to 0.73)	
Width of head	0.37 (0.34 to 0.38)	
Length of abdomen	2.18 (2.08 to 2.23)	
Width of abdomen	0.32 (0.29 to 0.34)	

Type-host: *Puffinus l'herminieri subalaris* Ridgway.

Material examined: Holotype male, allotype female and 3 male, 4 female paratypes, from MCZ skins nos. 112417 and 112418, collected near the Galapagos Islands, from the type-host, (RLE); 5 males, 2 females, paratypes, from type-host, same locality, in Kellogg collection.

Discussion: The type specimens of *Lipeurus diversus* var *major* Kellogg and Kuwana, from the same host, will be discussed under *Halipeurus intermedius* nom.

nov. *H. attenuatus* is closely allied morphologically to *H. mundae* sp. nov., but may be distinguished from it by the shape of the signature and the male genitalia.

Halipeurus (*Halipeurus*) *mundae* sp. nov.
(Figs. 3–7, N)

Description: Unusual louse belonging to *diversus* species group. Head ratio 2.1. Basal segment of antenna almost bulbous. Signature more-or-less typical with indistinct medial indentation. Abdomen ratio 5.4, subspatulate. Medial processes on all buttresses. Sixth segment one-half the length of 5th. Sternite 9 and 10 squared posteriorly, with typical, but slightly drawn out and irregular setal pattern. Parameres short, with spatulate, irregularly margined tips. Aedeagal sac obviously sclerotized, almost as long as longest paramere. Female typical.

Measurements: 2 males, 2 females from the type-host, averages in millimeters:

	Males	*Females*
Total length	3.93	4.08
Length of head	0.78	
Width of head	0.37	
Length of abdomen	2.50	
Width of abdomen	0.46	

Type-host: *Puffinus assimilis mundae* (Salvin).

Material examined: Holotype male, allotype female, 1 male, 1 female, paratypes, from AMNH skin no. 211652, collected by R. H. Beck and J. G. Correia, at 49° S, 179° W, (RLE). *Puffinus assimilis elegans* Giglioli and Salvadori, 2 females, Inaccessible Island, collected by F. H. I. Elliot, 5 July 50.

Discussion: This species represents an unusual development of the *diversus*-type, with short, modified parameres, and enlarged basal segment of the male antenna.

Halipeurus (*Halipeurus*) *turtur* sp. nov.
(Figs. 3–7, O)

Description: A small species closely related to *H. accentor* sp. nov. Head ratio 2.1. Antenna with cylindric basal segment. Abdomen ratio 5.8, relatively narrow. Buttresses IV–VIII with well developed medial processes. Genitalia broad, with parameres essentially symmetrical, tips broadened, spatulate. Obvious and distinctive sclerotization within aedeagal sac, reminiscent of that found in *H. accentor.* Setae 5 and 6 of group II moved to lateral margin of sternite 9 and 10, leaving 1 to 4 joined by the two setae normally anteriad, forming two closely set rows of three setae each. Female with obvious medial indentation in signature.

Measurements: 2 males, 1 female, averages only in millimeters:

	Males	*Females*
Total length	3.38	4.00
Length of head	0.70	
Width of head	0.34	
Length of abdomen	2.16	
Width of abdomen	0.37	

Type-host: *Pachyptila turtur turtur* Kuhl.

Material examined: From type-host, holotype male, allotype female, 1 female paratype, from AMNH skin no. 334593, collected by R. H. Beck, 35° S, 175° W, (RLE).

Discussion: A small distinctive species, that, like *H. bulweria,* appears to be derived from a species found typically on *Puffinus* or *Pterodroma.* In this case, it appears that *H. accentor* from *Pterodroma leucoptera* and *cookii* is the most closely related species.

Halipeurus (*Halipeurus*) *procellariae* (Fabricius)
(Figs. 3–7, P)

Pediculus procellariae Fabricius, 1775, (nec *procellariae* Gurlt (1837), nec *procellariae* Leach MS., Denny (1852) both *nomina nuda*), Systema Entomologiae, Flensburg, p. 808.

Type-host: See discussion below. Considered unrecognizable. Thompson, 1938, Ann. Mag. Nat. Hist., ser. 11, **2**, p. 491.

Miss Theresa Clay, working with Mr. G. H. E. Hopkins, is doing a commendable job revising the early literature of Mallophaga and wishes to place *Pediculus procellariae* Fabricius. The description is brief, translated from Latin as follows: "—a filiform, fuscous, pale footed species on a Brazilian procellariform." While description is apt for *Halipeurus,* and since *Esthiopterum constrictiventre* Pessoa and Guimaraes from *Pterodroma macroptera* is synonymous with *H. diversus* (Kellogg), the louse typically found on this host is undescribed. This louse is also commonly found on four species of *Pterodroma,* namely *mollis, incerta, lessoni* and *macroptera,* that range widely over the South Atlantic making it a very likely possibility. No neotypes will be erected.

Description: Another species of the *H. marquesanus* group. Head ratio 1.9, broad, strikingly 'egg-shaped'. Signature elongate with tapering posterior extension. Premarginal carina not interrupting head outline as usual. Ventral carina distinct. Basal segment of antenna subcylindric, 2d segment relatively large. Pterothoracic patch typical. Abdomen ratio 5.9, barely subspatulate. Buttresses relatively large and with well developed medial processes. Sixth segment one-half the length of the 5th. Sternite 9 and 10 heavily sclerotized, with basic 'T' shape, the shaft of the 'T' expanded and bell-shaped, overlapping the 11th segment slightly. Genitalia broad, parameres relatively short, broadened distally and curving medially, symmetrical. Aedeagal sac about two-fifths the length of parameres. Females typical.

Measurements: 10 males, 8 females from *Pterodroma incerta,* averages and ranges in millimeters:

	Males	*Females*
Total length	4.10 (3.69 to 4.45)	4.60 (4.15 to 4.77)
Length of head	0.82 (0.75 to 0.88)	
Width of head	0.43 (0.37 to 0.47)	
Length of abdomen	2.60 (2.46 to 2.85)	
Width of abdomen	0.44 (0.41 to 0.48)	

Type-host: Pterodroma macroptera (Smith).

Material examined: Pterodroma incerta (Schlegel): 11 males, 9 females, collected 36° S, 46° W, no further data (RLE): 2 males and 1 female, (GBT). Other hosts as follows:

Pterodroma lessoni lessoni (Garnot): 2 males, 4 females, collected by R. H. Beck from the Antipodes Islands, New Zealand, (RLE).

Pterodroma lessoni australis (Mathews): 6 males, 3 females, collected by R. H. Beck from the Antipodes Islands, New Zealand; 1 female, same locality, (GBT).

Pterodroma caribbaea Carte: 2 females, from MCZ skin collected at Jamaica, 1879, (RLE).

Pterodroma macroptera (Smith): 1 male and 1 female, no data, (GBT).

Pterodroma macroptera gouldi (Hulton): 2 males and 2 females, New Zealand, (GBT).

Pterodroma macroptera albani Mathews: 5 males and 1 female, Albany, (GBT).

Pterodroma mollis mollis (Gould): 2 males, 2 females from AMNH skin no. 132496, collected at 36° S, 46° W, (RLE).

Halipeurus (*Halipeurus*) *kermadecense* (Johnston and Harrison)

(Figs. 3–7, ♀)

Lipeurus kermadecense Johnston and Harrison, 1912, Tr. & Proc. New Zeal. Inst., **44**, p. 365, fig. 1. Immature. *Type-host: Aestrelata neglecta* Schlegel.

Lipeurus diversus var. *excavatus* Johnston and Harrison, as above, p. 366, fig. 2. *Type-host: Aestrelata neglecta* Schlegel. Adult of *kermadecense.*

Esthiopterum kermadecense (Johnston and Harrison). Harrison, 1916, Parasit., **9**, No. 1, p. 136.

Halipeurus kermadecense (Johnston and Harrison). Thompson, 1938, Ann. Mag. Nat. Hist., ser. 11, **2**, p. 488.

Description: Head ratio 2.1. Signature with medial posterior extension. Well developed ventral carina. Premarginal carina as in *H. procellariae,* narrow and not interrupting outline of head. Antenna relatively long and slender. Abdomen ratio 5.5. Buttresses broad, with well-developed medial processes. Sixth segment about one-half the length of 5th. Terminal segments generally darkened ventrally, but without obvious development seen in closely related *H. procellariae.* Genitalia broad, parameres with spatulate tips, only slightly subequal, not as symmetrical as in procellariae. Tube-like sclerotization within aedeagal sac, obliquely cut distally. Setal pattern typical. Signature of female squarer than in male but with similar outline.

Measurements: 10 males, 10 females from various hosts, averages and ranges in millimeters:

	Males	*Females*
Total length	3.66 (3.54 to 3.70)	4.36 (4.24 to 4.62)
Length of head	0.77 (0.75 to 0.82)	
Width of head	0.37 (0.34 to 0.39)	
Length of abdomen	2.22 (2.15 to 2.31)	
Width of abdomen	0.40 (0.37 to 0.44)	

Type-host: Pterodroma phillipii Gray.

Material examined: From the type-host: 4 males, 5 females, from MCZ skin no. 82907, Masa Tierra Island, (RLE); 8 males, 3 females, no locality, (GBT). From other hosts as follows:

Pterodroma arminjoniana (Giglioli and Salvadori): 2 males, 2 females, from South Trinidad Island, (Meinertzhagen); 1 male, 2 females, South Trinidad Island, (GBT).

Pterodroma externa externa (Salvin): 2 males, from MCZ skin no. 82905, Masa Tierra Island, (RLE).

Discussion: The classification of the genus *Pterodroma* used by Peters (1931) needs radical revision; it is used here for the sake of uniformity.

The specimens from *P. externa* listed above are probably stragglers, this host normally is infested with *H. intermedius* nom. nov.

H. kermadecense may be separated from *H. procellariae* by virtue of the similar, but distinctly asymmetrical parameres.

Halipeurus (*Halipeurus*) *accentor* sp. nov.
(Figs. 3–7, R)

Description: Head ratio 2.1, relatively narrow. Signature more-or-less typical of *Pterodroma* species, extended posteriorly with slight medial indentation. Barely distinct ventral carina. Pterothoracic setal patch with three closely set setae. Abdomen ratio 6.0, relatively straight sided. Sixth segment about one-half as long as 5th. Sternite 9 and 10 overlapping 11th with rounded posterior border. Sclerotized laterally, superficially resembling *H. forficulatus* sp. nov. Setal pattern typical. Genitalia broad with moderately sclerotized basal apodeme. Parameres subequal, spatulate and pointed, variable depending on orientation within body. Aedeagal sac about three-fourths the length of parameres. Females typical.

Measurements: 8 males, 7 females, from various hosts, averages and ranges in millimeters:

	Males	*Females*
Total length	3.78 (3.69 to 3.92)	4.15 (3.99 to 4.30)
Length of head	0.72 (0.68 to 0.75)	
Width of head	0.35 (0.34 to 0.37)	
Length of abdomen	2.42 (2.31 to 2.62)	
Width of abdomen	0.40 (0.37 to 0.42)	

Type-host: Pterodroma leucoptera masafuerae Lonnberg.

Material examined: From the type-host, holotype male, allotype female, 7 male and 5 female paratypes, from AMNH skin no. 446141, collected near Masa Tierra Island, Chile, (RLE). Other material as follows:

Pterodroma leucoptera hypoleuca (Salvin): 1 male, 1 female, paratypes, from the Bonin Islands, (GBT).

Pterodroma cookii nigripennis (Rothschild): Paratype female from MCZ skin no. 39895, collected near Kermadec Islands, (RLE); 3 male, 3 female paratypes, Kermadec Islands, (GBT).

Pterdroma cookii difilipianna (Giglioli and Salvatori): 3 paratype males from MCZ skin no. 82092, collected near Masa Tierra Island, (RLE); male and female, 80 miles west Ancon, Peru, (Curran-AMNH).

Halipeurus (*Halipeurus*) *intermedius* nom. nov.
(Figs. 3–7, S)

Lipeurus diversus var. *major* Kellogg and Kuwana, 1902, (nec Piaget, 1880) Proc. Wash. Acad. Sci., 4, p. 477. Type-host: *Puffinus subalaris.*

Halipeurus sp?. Thompson, Ann. Mag. Nat. Hist., ser. 11, **2**, p. 485.

Description: Head ratio 2.1, narrow. Signature squarish, posterior extension narrowed. Premarginal carina barely separated from post-marginal carina. Basal segment of antenna essentially cylindric, but very wide, 2d and 3d segments enlarged relatively. Pterothoracic patch divided. Abdomen ratio 6.2. Buttress with posterior medial processes well developed, more or less pointed. Segment 6 only slightly smaller than 5. Sternite 9 and 10 with faint 'T' shaped sclerotization, slightly overlapping 11. Setal pattern typical but variable. Eleventh segment short and triangular, with narrow buttresslike sclerotization. Genitalia broad with long distinct basal apodeme. Parameres moderately long, broad, sub-equal, with tips pointed and turned mediad slightly. Aedeagal sac about three-fourths length of parameres. Female with terminal segments as in *H. marquesanus* and *postmarquesanus.*

Measurements: 6 males, 5 females from hosts listed:

	Males	*Females*
Total length	4.82 (4.62 to 4.92)	4.94 (4.85 to 5.00)
Length of head	0.81 (0.78 to 0.85)	
Width of head	0.38 (0.38 to 0.41)	
Length of abdomen	3.16 (3.08 to 3.23)	
Width of abdomen	0.51 (0.49 to 0.52)	

Type-host: Pterodroma phaeopygia phaeopygia (Salvin).

Material examined: From the type host, holotype male, allotype female, from AMNH skins collected by R. H. Beck from the Galapagos (RLE); 4 paratype males from MCZ skin no. 65683, Galapagos (RLE); male paratype, Galapagos (GBT).

Pterodroma externa cervicales (Salvin): 2 males paratypes, collected by R. H. Beck near Sunday, Kermadec Islands (AMNH); 3 male, 3 female paratypes, Kermadec Islands (GBT); 3 male, 5 female paratypes, from MCZ skin no. 39893, Kermadec Islands (RLE).

Puffinus subalaris Ridgway: 1 male, 1 female, syntypes of Kellogg and Kuwana's *Lipeurus diversus* var. *major,* (these are, without doubt, stragglers).

Discussion: These species may be separated from the other closely related species, *H. marquesanus* and *postmarquesanus* by the genitalia and chaetotaxy of the male terminal segments.

Halipeurus (*Halipeurus*) *marquesanus* (Ferris)
(Figs. 3–7, T)

Esthiopterum marquesanus Ferris, 1932, Bull. Bishop Mus. Honolulu, **98**, pp. 62–63, figs. 14, 15. *Type-host: Pterodroma rostrata. Halipeurus marquesanus* (Ferris). Thompson, 1938, Ann. Mag. Nat. Hist., ser. 11, **2**, p. 489.

Description: Head ratio 2.1, narrow. Signature relatively short, with prolonged medial portion posteriorly. Pre- and postmarginal carinae more-or-less fused. Dorsal carinae extend to level of mandibles in male, but are much shorter in female. Pterothoracic patch atypical in male, usually in two parts, one part with a single long seta, the other with two setae. Abdomen ratio 7.3, exceptionally narrow, straight-sided. Sixth segment slightly smaller than 5th. Buttresses relatively narrow with only moderately developed medial processes. Sternite 9 and 10 with rectangular extension posteriorly, overlapping segment 11. Setal pattern of group II crowded, slightly distorted, with setae 1 and 2 close set, and 5 and 6 moved anteriorly. Parameres long and slender, with slightly broadened tips. Aedeagal sac about two-thirds as long as parameres. Sternite 9 of female expanded and extended as an obvious loose flap over next segment. Buttresses 9 and 10 and 11 smoothly fused, as same tergites almost are.

Measurements: 5 males and 8 females from the type-host, averages and ranges in millimeters:

	Males	*Females*
Total length	4.00 (3.85 to 4.16)	4.46 (4.15 to 4.62)
Length of head	0.74 (0.71 to 0.75)	
Width of head	0.34 (N.V.)	
Length of abdomen	2.62 (2.62 to 2.69)	
Width of abdomen	0.36 (0.34 to 0.37)	

Type-host: Pterodroma rostrata rostrata (Peale).

Material examined: 1 male, 2 female paratypes kindly loaned by Mr. Gordon B. Thompson;

26 males, 29 females, from MCZ skin no. 166885, from the Society Islands, (RLE), all from type-host.

Halipeurus (*Halipeurus*) *postmarquesanus* sp. nov.
(Figs. 3–7, U)

Description: Very close to *H. marquesanus.* Head ratio 2.0. Pre- and postmarginal carinae not fused. Pterothoracic patch variable, usually divided into two groups. Abdomen ratio 6.8, very similar to *H. marquesanus* except for the elongated segment 9 and 10. Group II setae crowded posteriorly. Parameres and basal apodeme forming very long, narrowly 'S' shaped unit. Female with terminal segments like those of *H. marquesanus.*

Measurements: 5 males and 6 females from the type-host, averages and ranges in millimeters:

	Males	*Females*
Total length	3.72 (3.62 to 3.85)	4.30 (4.15 to 4.38)
Length of head	0.68 (0.65 to 0.70)	
Width of head	0.34 (0.32 to 0.35)	
Length of abdomen	2.43 (2.32 to 2.46)	
Width of abdomen	0.36 (0.34 to 0.37)	

Type-host: *Pterodroma heraldica* (Salvin).

Material examined: Holotype male, allotype female, 3 male, 4 female paratypes, from AMNH skin collected in the South Pacific, (RLE); 1 male and 2 female paratypes, Chesterfield Group, (GBT).

Pterodroma parvirostris (Peale): 1 male, 1 female, no data, (GBT).

Discussion: Readily separated from both *H. marquesanus* and *intermedius* by the distinctly shaped male genitalia.

List of the Species and Subspecies of Halipeurus (Halipeurus) *and Their Hosts*
(* *Type-Host*)

H. angusticeps angusticeps (Piaget)
  Host unknown.
H. a. fosteri subsp. nov.
  * *Puffinus leucomelas* (Temminck)
H. abnormis (Piaget)
  * *Puffinus gravis* (O'Reilly)
  Puffinus kuhlii kuhlii (Scopoli)
  Puffinus kuhlii borealis Cory
  Puffinus kuhlii edwardsi Oustalet
  Puffinus kuhlii flavirostris (Gould)
H. mirabilis Thompson
  Puffinus pacificus pacificus (Gmelin)
  * *Puffinus pacificus chlorohynchus* Lesson
  Puffinus pacificus cuneatus Salvin
H. placodus sp. nov.
  Puffinus assimilis assimilis Gould
  * *Puffinus assimilis tunneyi* Mathews
  Puffinus assimilis kermadecensis Murphy
  Puffinus l'herminieri nugax Mathews
  Puffinus auricularis Townsend
H. diversus (Kellogg)
  * *Puffinus griseus* (Gmelin)
  Puffinus tenuirostris (Temminck)
  Puffinus puffinus puffinus (Brunnich)
  Puffinus puffinus yelkouen (Acerbi)
  Puffinus puffinus mauretanicus Lowe
H. forficulatis sp. nov.
  * *Puffinus l'herminieri polynesiae* Murphy
  Puffinus l'herminieri dichrous Finsch and Hartlaub
  Puffinus heinrothi Reichenow

H. bulweriae sp. nov.
  * *Bulweria bulweria* (Jardine and Selby)
H. taxosetus sp. nov.
  * *Puffinus nativitatis* Streets
  Puffinus gavia Forster
  Puffinus opisthomelas Coues
  Puffinus l'herminieri l'herminieri Lesson
  Puffinus l'herminieri bannermani Mathews & Iredale
  Puffinus l'herminieri bailloni (Bonaparte)
  Puffinus assimilis baroli (Bonaparte)
H. falsus falsus Eichler
  * *Pelecanoides garnotti* (Lesson)
H. f. pacificus subsp. nov.
  * *Pelecanoides urinatrix* (Gmelin)
  Pelecanoides magellani (Mathews)
  Pelecanoides exsul Salvin
H. thompsoni sp. nov.
  * *Puffinus bulleri* Salvin
H. micariproctus sp. nov.
  * *Puffinus carneipes* Gould
  Puffinus creatopus Coues
  Puffinus gravis (O'Reilly)
H. attenuatus sp. nov.
  * *Puffinus l'herminieri subalaris* Ridgway
H. mundae sp. nov.
  * *Puffinus assimilis munda* (Salvin)
  Puffinus assimilis elegans Giglioli and Salvadori
H. turtur sp. nov.
  * *Pachyptila turtur turtur* (Kuhl) (Tentative)
H. procellariae (Fabricius)
  Pterodroma incerta (Schlegel)
  Pterodroma lessoni lessoni (Garnot)
  Pterodroma lessoni australis (Mathews)
  Pterodroma caribbaea Carte
  * *Pterodroma macroptera macroptera* (Smith)
  Pterodroma macroptera gouldi (Hutton)
  Pterodroma macroptera albani Mathews
  Pterodroma mollis mollis (Gould)
  Pterodroma inexpectata (Forster)
H. kermadecense (Johnston and Harrison)
  * *Pterodroma phillipii* (Gray)
  Pterodroma arminjoniana (Giglioli and Salvadori)
  Pterodroma externa externa (Salvin)
H. accentor sp. nov.
  * *Pterodroma leucoptera masafuerae* Lonnberg
  Pterodroma leucoptera hypoleuca (Salvin)
  Pterodroma cookii nigripennis (Rothschild)
  Pterodroma cookii difilipianna (Giglioli and Salvadori)
H. intermedius nom. nov.
  * *Pterodroma phaeopygia phaeopygia* (Salvin)
  Pterodroma externa cervicalis (Salvin)
H. marquesanus (Ferris)
  * *Pterodroma rostrata rostrata* Peale
H. postmarquesanus sp. nov.
  * *Pterodroma heraldica* (Salvin)
  Pterodroma parvirostris (Peale)

Subgenus Synnautes *Thompson*

Synnautes Thompson, 1936, Ann. Mag. Nat. Hist., ser. 10, **18**, p. 43. Genotype: *Lipeurus pelagicus* Denny.

Naubates Bedford, *partim.* T. Clay, 1940, Brit. Graham Land Exped., 1911–14, ser. C, **2**, pt. 1, p. 31.

Description: Similar to subgenus *Halipeurus*, differing as follows: Buttresses of abdomen very narrow, with medial processes limited to small, knob-like enlargements at posterior ends of buttresses. Ventral carina usually heavily sclerotized; dorsal carina typically extending only to mid-point between signature and mandibles (exception *nesofregettae* sp. nov.). Pre- and postmarginal carinae more or less fused; premarginal carina obliquely truncate anteriorly, interrupting outline of head (fig. 6). Female abdomen sharply bifid, always with very stout, short seta terminating each buttress of segment 11. Cuticle obviously scaly, more so than in subgenus *Halipeurus.*

Type of subgenus: Halipeurus (Synnautes) pelagicus (Denny) 1842.

Discussion: The species of subgenus *Synnautes* are limited to birds of the family *Hydrobatidae.* They seem best adapted for living on the back and proximal portions of the wings, as are species of subgenus *Halipeurus.*

The new species herein described is the second, and several more remain to be described. The subgenus has species that reflect many of the variations of subgenus *Halipeurus,* indicating that considerable parallel evolution has taken place between the two subgenera.

Halipeurus (Synnautes) pelagicus (Denny)

(Figs. 3–7, V)

Lipeurus pelagicus Denny, 1842, Mono. Anoplurorum Brit., pp. 173–174, pl. 14, fig. 2. *Type-host: Thalassodroma pelagica* (cf. Thompson, 1937, on the Denny collection).

Lipeurus subangusticeps Piaget, 1880, Les Pediculines, pp. 308–309, pl. 25, fig. 5. *Type-host: Thallassodroma leachi* (from Rotterdam Zoo).

Lipeurus languidus Kellogg and Kuwana, 1902, Proc. Wash. Acad. Sci., **4**, pp. 475–476, pl. 29, fig. 8. *Type-hosts: Oceanodroma tethys* and *Oceanites gracilis.*

Lipeurus exiguus Kellogg and Kuwana, as above, p. 479, pl. 30, fig. 2. Immatures. *Type-host: Oceanites gracilis.*

Esthiopterum pelagicum (Denny). Harrison, 1916, Parasit., **9**, No. 1, p. 139.

Synnautes pelagicus (Denny). Thompson, 1936, Ann. Mag. Nat. Hist., ser. 10, **18**, p. 43. Genotype of genus *Synnautes* Thompson.

Description: As for subgenus, further details as follows: Slender, very dark lice, widely distributed on *Hydrobatidae.* Head ratio 2.2, very slender, with nearly parallel sides. Signature triangular anteriorly, with very broad hyaline border, straight-sided, with tapered posterior extension and small, narrow medial indentation. Thorax with narrow buttresses. Abdomen ratio 5.0, very slender. Tergites evenly sclerotized, with band narrowed slightly only on segments 6, 7, and 8. Buttresses very small, best developed on ends of buttresses of segments 6, 7, and 8. Buttresses 9 and 10 smoothely tapered. Sternite 9 and 10 distinctly sclerotized, with setal pattern similar to that of *H. (Halipeurus) taxosetus,* with slight modification. Parameres long, slender, flattened, and somewhat irregularly curved from specimen to specimen. Female typical of subgenus, with signature very much like that of male.

Measurements: 5 males, 3 females, from *Pelagodroma m. marina,* averages and ranges in millimeters as follows:

	Males	*Females*
Total length	3.52 (3.32 to 3.63)	4.03
Length of head	0.78 (0.75 to 0.82)	0.80
Width of head	0.37 (0.34 to 0.39)	0.45
Length of abdomen	2.14 (2.02 to 2.24)	2.67
Width of abdomen	0.42 (0.37 to 0.44)	0.54

Type-host: Hydrobates pelagicus (Linné).

Material examined: From the type-host, 2 males, 1 female, from MCZ skin no. 235247, Basket Islands, Ireland (RLE). Other material as follows:

Bulweria bulweria (Jardine and Selby): 2 females, from MCZ skin no. 98117, collected near Madeira Island, (RLE). Stragglers?

Oceanites oceanicus oceanicus (Kuhl): 2 females, mar del Plata, Argentina, (AMNH).

Oceanites gracilis gracilis (Elliot): 1 male, 4 females, from AMNH skin no. 206965, collected near Pacas Mayo, Peru, (RLE).

Oceanites gracilis galapagoensis Lowe: 1 female, from Galapagos Islands, (AMNH).

Pelagodroma marina marina (Latham): 4 males, 3 females, from AMNH skin no. 254335, from Herald Islands, New Zealand, (RLE); 5 males, 6 females, from skin in Preparations Department of AMNH, collected at Tristan da Cunha.

Pelagodroma marina maoriana Mathews: 2 females from AMNH skin, no further data, (RLE); 7 males, 6 females, from 37° S–179° W, (AMNH).

Fregetta grallaria grallaria (Vieillot): 2 males, 4 females, from AMNH skin no. 446402, collected near Masa Tierra Island, Chile, (RLE); 8 males, 8 females, from Masa Tierra Island, Chile, (AMNH).

Fregetta grallaria titan Murphy: 1 male, from Rapa Island, (AMNH).

Fregetta tropica melanogaster (Gould): 1 male, 2 females, from AMNH skin no. 212047, 49° S–179° W, (RLE).

Oceanodroma tethys tethys (Bonaparte): 3 males, from AMNH skin no. 196377, 2° S–91° W, (RLE). 3 males, 5 females, from MCZ skin no. 111806, Galapagos Islands, (RLE).

Oceanodroma castro castro (Harcourt): 3 males, 2 females, from MCZ skin no. 300905, from Porto Santo, Madeira, (RLE).

Oceanodroma castro bangsi Nichols: 1 female, Galapagos, (AMNH).

Oceanodroma leucorhoa keadingi Anthony: 1 male, Guadalope Island, (AMNH).

Oceanodroma macrodactyla Bryant: 1 male from AMNH skin, no data, (RLE).

Oceanodroma markhami tristrami Salvin: 1 female, from Hawaiian Islands, (AMNH).

Oceanodroma hornbyi (Gray): 1 male, from 80 miles west of Ancon, Peru, (AMNH).

Oceanodroma furcata (Gmelin): 1 female, from MCZ skin no. 321672, collected near Sitka, Alaska, (RLE).

Halocyptena microsoma Coues: 1 damaged male, from MCZ skin no. 101692, from San Benito Island, (RLE); 1 female from AMNH skin, same locality, (RLE).

Discussion: *Synnautes* species are closely related to the *procellariae* species group of *Halipeurus,* as evidenced by their general structure, sclerotization of terminal segments, shape of head, type of signature and male genitalia.

Synnautes pelagicus is notable in that it may be found on so many different host species. The other two species of *Synnautes* in my collection, *nesofregettae* and one undescribed, are each restricted to one host species.

Halipeurus (*Synnautes*) *nesofregettae* sp. nov.

(Figs. 3–7, W)

Description: Typical *Synnautes* with some features of typical *Halipeurus.* Head ratio 2.2, narrow, with straight-sided lateral margin. No hiatus between pre- and postmarginal carinae. Dorsal carinae extend to level of mandibles and then unite medially. Ventral carina very distinct. Signature squarish, with posterior extension like that of species of *Halipeurus* from *Pterodroma.* Antenna with long cylindric basal and 2d segment. Pterothoracic patch typical. Abdomen ratio 5.0. Buttresses very narrow, with only slight medial processes, restricted to ends of buttresses. Sixth segment three-fourths as long as 5th. Sternite 9 and 10 overlapping most of 11th segment, with irregular, atypical setal pattern. Parameres moderate in length and breadth, distinctly sub-equal.

Measurements: 5 males, 3 females from type-host, averages and ranges in millimeters:

	Males	*Females*
Total length	3.85 (3.77 to 3.93)	4.16 (4.08 to 4.24)
Length of head	0.83 (0.80 to 0.85)	
Width of head	0.37 (0.36 to 0.38)	
Length of abdomen	2.37 (2.31 to 2.46)	
Width of abdomen	0.47 (0.43 to 0.48)	

Type-host: *Nesofregetta albigularis* (Finsch).

Material examined: From the type-host: Holotype male, allotype female, 4 male and 2 female paratypes, from AMNH skin no. 205901, collected at Phoenix, Phoenix Group, (RLE); 1 female, paratype, from New Hebrides, (GBT).

Discussion: This species closely unites the taxonts *Synnautes* and *Halipeurus,* (cf. Clay 1940, pp. 309–310). It resembles *Halipeurus* in that the dorsal carina definitely extends to the level of the mandibles, and in that the pre- and postmarginal carinae are not united. The female, however, has the typical *Synnautes* terminal segments, with the broadened seta apically on each 11th buttress.

SUMMARY

The genus *Halipeurus,* typically parasitizing the shearwaters and petrels, is revised. Twelve new species and two new subspecies are described. All previously described species are redescribed and refigured and, where necessary, lectotypes designated. Host-parasite relationships are discussed.

LITERATURE CITED

CLAY, T. 1940 Anoplura. British Graham Land Expedition, 1934–37. Sci. Repts. **1**: 295–315.

——— 1951 An introduction to a classification of the avian Ischnocera (Mallophaga): Part 1. Tr. Roy. Ent. Soc. Lond. **102**: 171–194.

HARRISON, L. 1937 Mallophaga and Siphunculata. Australasian Antarctic Expedition, 1911–14, ser. C **2**: 5–46.

MURPHY, R. C. 1927 On certain forms of *Puffinus assimilis* and its allies. Am. Mus. Nov. (276): 1–15.

SALMON, J. T. 1951 Polyvinyl alcohol as a mounting medium in microscopy. Mimeo. reprint of article in the Microscope, New Zealand, March–April.

SYMMONS, S. 1952 Comparative anatomy of the Mallophagan head. Tr. Zool. Soc. Lond. **27**: 349–436.

WILSON, F. H. 1934 The life-cycle and bionomics of *Lipeurus heterographus* Nitzsch. J. Parasit. **20**: 304–311.

——— 1939 The life-cycle and bionomics of *Lipcurus caponis* (Linn.). An. Ent. Soc. Am. **32**: 318–320.

32

Robert L. Edwards and J. L. Chamberlin,
U.S. Bureau of Commercial Fisheries

Grant No. 1547 (1953), $1,500. Ecological investigation of Richmond Gulf, Hudson Bay.

This grant was used to support the second of three planned trips to investigate the ecology of the Richmond Gulf region on the east coast of Hudson Bay. Additional support was given by the Woods Hole Oceanographic Institution, the American Academy of Arts and Sciences, and the Geological Society of North America.

The grantees are indebted again to the Hudson's Bay Company for their assistance in making arrangements for the caching of supplies at Great Whale River and Richmond Gulf. As before, Mr. and Mrs. George Papp of Richmond Gulf, and Mr. Fred Woodrow, radio operator at Great Whale River, helped to smooth an otherwise arduous trip. Mr. Woodrow maintained scheduled radio contacts with the grantees throughout the summer, who are also indebted to the Oblate Fathers of the missions at Moosonee, Ontario, and Fort George, Quebec, for many kindnesses.

The initial expedition plans called for chartering a small vessel at Moosonee. These plans were altered when, so inexpensively that it could be considered expendable, a 30-foot Navy whaleboat was obtained that had been converted to a shrimp dragger. This small boat, christened the R/V *Lemming*, was overhauled for oceanographic research operations at the Woods Hole Oceanographic Institution. The Institution also supplied a hydrographic winch, instrumentation and other gear necessary to undertake adequately a limited program of hydrographic research. The R/V *Lemming* was then transported to Moosonee on a railroad flatcar.

The expedition's supplies and gear were transported from Boston to Cochrane, Ontario, by truck, then by rail to Moosonee. The truck was generously supplied by the father of one of the grantees, Mr. R. D. Edwards, who went on the first leg of the trip. The logistic problems were considerable, but with the exception of having some hard-to-replace equipment stolen from the vessel, while in transit by rail, it was still possible, with only a moderate delay, to depart from Moosonee and begin research on August 7.

The most memorable aspect of the trip was the great abundance of small mammals, in this peak year of the four-year rodent cycle. The lifeless evidence (corpses, scat piles, etc.) of the previous peak year, 1949, observed in 1950, was impressive but it did not adequately prepare us for the main event. Small mammals were seen in abundance at every stop. To observe many species it was only necessary to remain reasonably quiet. Expectations were that the lemming (*Dicrostonyx*) would predominate, but this was not so, at least in 1953. Rather the more open tundra areas were alive with lemming-mice (*Synaptomys*) and the phenacomys vole (*Phenacomys*) and wherever the spruce or alder offered shelter, the red-backed mouse (*Clethrionomys*) abounded. The open, grassy areas along the shore were overrun with meadow mice (*Microtus*)

Reprinted from Year Book of The American Philosophical Society, 1961
285-287

Printed in U. S. A.

to such an extent that an Indian boy was able to collect eighteen by hand one afternoon.

The range in pelage variation of the red-backed mouse in the collections was even more extensive than that reported by Outram Bangs in 1897 (*Proc. Biol. Soc. Wash.*). This phenomenon suggests that marked gene segregation may accompany these population explosions; certainly this particular microtine is worthy of further study in this respect.

The range of the star-nosed mole (*Condylura cristata*) was extended at least as far north as Richmond Gulf.

Three species of fishes, *Ammodytes hexapterus, Lumpenus medius,* and *Careproctus reinhardi,* were added to the list from Hudson Bay, none of which do any violence to the generally accepted opinion that Hudson Bay fishes re-entered the area from Atlantic refugia following the last glacial period. This hypothesis was further substantiated by meristic data obtained from the collections of those species with wide polar distributions, especially sculpins.

Three species, *Boreogadus saida, Icelus spatula,* and *Careproctus reinhardi,* were taken in water of below 0° C.

More than forty hydrographic stations were occupied in the Richmond Gulf area. Extensive recordings of depths were obtained on transects across Richmond Gulf and between Richmond Gulf and the Belcher Islands. The recordings were obtained using a depth sounder, "Fathometer Jr.," Model 1373, generously loaned by the Submarine Signal Division of the Raytheon Mfg. Co.

The hydrography of Richmond Gulf was comparable to that of Hudson Bay, differing in the more pronounced thermocline and in the decreased surface salinities. The deep waters did not appear to be stagnant despite the very shallow (*circa* 10 fathoms) threshold in the connection between the Gulf and Hudson Bay. Fish and invertebrates, sometimes in considerable abundance, were collected at all depths.

The topography of the scarps along the western side of Richmond Gulf suggested that it might be very deep in spots. As it turned out, it was possible to make collections in 60 fathoms a scant one hundred yards offshore at several points. The greatest depth recorded within the Gulf was over 70 fathoms.

A depth sounding transect between Richmond Gulf and the Belcher Islands indicated that depths in excess of 100 fathoms may be expected in this area. The deepest recorded depth on this particular transect was 106 fathoms.

During the trip to and from Richmond Gulf, several depth recording transects were made in James Bay. Some very deep areas exist in James Bay, greatly in excess of what has been recorded to date. One depression of 50 fathoms lies just northwest of Charlton Island, and a second, of better than 40 fathoms, between Trodely and Weston Islands.

The various raised beach series in the Richmond Gulf area were carefully studied. The most highly developed series had more than 35 individual terraces rising in a continuous series from the present shore line to approximately 365 feet. None of the series appeared to have been occupied by Eskimos now or in the past and do not seem to offer much promise for extended archaeological examination. One series in particular was carefully examined to determine the dynamics of terrace formation in this region. We concluded that these terraces were formed as a result of the interaction of eustatic adjustment and occasional severe storms.

While the terraces themselves proved to be virtually free of animal remains, some now elevated underwater deposits were richly fossiliferous. Although all of the species contained are still living in this area these fossil specimens were significantly larger, on the average, than present-day individuals.

The grantees returned to Moosonee on the fourteenth of October, after a highly successful, but arduous, two months in the field. Valuable collections of fish, mammals, and marine invertebrates were obtained. These collections have been studied and as a result several manuscripts are in press or in preparation. It was demonstrated by example that a small vessel research operation is feasible along the southeast coast of Hudson Bay and in James Bay. A somewhat larger vessel would have greatly eased some of our logistic problems but the costs would have been prohibitive. Experiences indicate that much work remains to be done in this interesting part of North America, and that Richmond Gulf would serve as an excellent base of operations for almost any program of subarctic marine or terrestrial ecological research.

Pacific Subarctic Circulation

FELIX FAVORITE, Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington, U. S. A.

Since 1955 we have been collecting routine oceanographic data in the North Pacific Ocean aboard exploratory salmon-fishing vessels. Although the cruises are planned to answer fishery problems, we have made some advances in determining the water structure of the central North Pacific. The data also permit investigation of the continuity of water properties between Canadian stations in the northeastern Pacific and Japanese stations in the northwestern Pacific.

Utilizing available 1958 data the volume transport in the Subarctic Region has been computed from a reference level of 1200 meters. Volume transports across the boundaries of 5° squares are compared with total transports computed by Fofonoff (1960) for the same period, and the geometric level is adjusted to include the latter transport. This results in a reference level of variable depth which is probably still less than a depth of no-net-motion, if one is present, but may be more valid than an arbitrary geometric level.

The geostrophic flows computed from the two reference levels are compared, and relationships between water structure and the variable reference level are discussed.

IN: Abstracts of Symposium Papers Tenth Pacific Science Congress, Honolulu, Hawaii, 1961, p. 343-344.

Surface Temperature and Salinity off the Washington and British Columbia Coasts, August, 1958 and 1959[1]

By Felix Favorite

Bureau of Commercial Fisheries
Biological Laboratory, Seattle, Washington

ABSTRACT

Oceanographic data collected off the Washington and British Columbia coasts during August, 1958 and 1959, through Canadian and United States research programs provide the best synoptic coverage attained in this area. Comparison of August surface data for the two years shows that the effects of local runoff can be traced over several hundred miles offshore. This implies, but does not necessarily confirm, the absence of any appreciable net surface current parallel to the coast northward of the Strait of Juan de Fuca to Dixon Entrance, in summer.

The 1958 observations were made at the time of the anomalous Fraser River sockeye run through Johnstone Strait and provide a good picture of the existing coastal and offshore oceanographic conditions. It is suggested that the seaward extent of dilute surface water may determine the location where homeward migrating salmon enter coastal waters.

INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka*) returning to spawn in the Fraser River, British Columbia, have a choice of two routes around Vancouver Island, from the north through Johnstone Strait or from the south through the Strait of Juan de Fuca. The latter is considered the normal route, but in 1958 practically the entire run was reported to have approached Vancouver Island from the north, and an unprecedented percentage of an unusually large run proceeded through Johnstone Strait (Internat. Pacific Salmon Fish. Comm., 1959).

This behaviour may have been due to a progressive northward intrusion of warm water off the Canadian coast from 1955 to 1958 as shown on the sigma-*t* surface 26.60 by Tully *et al.* (1960).

Alternatively, it could be due to an unusual change in position or extent of the local runoff flowing out of Queen Charlotte Sound and the Strait of Juan de Fuca. The migration pattern of the Fraser River salmon run returned to normal in 1959 (Internat. Pacific Salmon Fish. Comm., 1960). The purpose of this report is to present the surface conditions off the Washington and British Columbia coasts during August, 1958 and 1959, and to determine if any significant differences occurred in these two years that could have affected the 1958 migration route of the salmon.

Barnes and Paquette (1954) have described the general circulation off the Washington coast and noted that the brackish water originating in the outflow

---

[1] Received for publication December 5, 1960.

J. Fish. Res. Bd. Canada, 18(3), 1961.
Printed in Canada.

of the Columbia River could be detected over 200 miles offshore. Doe (1955), presenting data from project "Offshore", has described the origin and identification of water masses off the British Columbia coast, and detected brackish water several hundred miles offshore which he believed originated in local runoff.

SURFACE DATA, 1958

At the time the Fraser River salmon run was entering coastal waters in 1958, there were numerous oceanographic cruises being conducted in the area. The M.V. *Attu* and M.V. *Pioneer*, chartered by the Seattle Biological Laboratory of the U.S. Bureau of Commercial Fisheries to conduct experimental fishing and oceanographic research for the International North Pacific Fisheries Commission, were returning to Seattle, having completed operations in the Aleutian area (Favorite and Pedersen, 1959). At the same time, the Pacific Oceanographic Group of the Fisheries Research Board of Canada was making observations from C.N.A.V. *Whitethroat* and C.N.A.V. *Oshawa* (Fisheries Research Board of Canada, 1958 a, b). Also, the Oceanographic Laboratories of the University of Washington, Seattle, Washington, were independently conducting an oceanographic cruise in R.V. *Brown Bear* (Fleming *et al.*, 1959). Figure 1 shows the locations of all surface observations made from these vessels in the area under consideration during August 1958. The observed surface salinity and temperature distributions are shown in Fig. 2.

TEMPERATURE

The temperature distribution (Fig. 2) shows three interesting features: The region of divergence of the isotherms in the vicinity of Lat. 50°N, Long. 135°W; the band of cool water along the coast; and the apparent northward intrusion of warm water seaward of the cold water along the coast.

The divergence of the isotherms appears to be associated with a tongue of dilute water extending seaward, and is not to be confused with the divergence of the Westwind Drift which occurs farther offshore. The band of cold temperatures along the coast has been explained by Tully (1937) and Barnes and Paquette (1954) as a normal late summer condition, and has been attributed to upwelling.

Reference is made only to the August, 1950 and 1951, data presented by Doe (1955) and the average August conditions presented by Robinson (1957) in determining whether or not the 1958 conditions were anomalous. Although limited data are available for other years, only the above data are considered to be adequate enough to permit comparison. The 1951 temperatures are representative of average conditions and the 1958 temperatures were approximately 1 to 2 C° higher than average; however, the general configuration of the isotherms was similar.

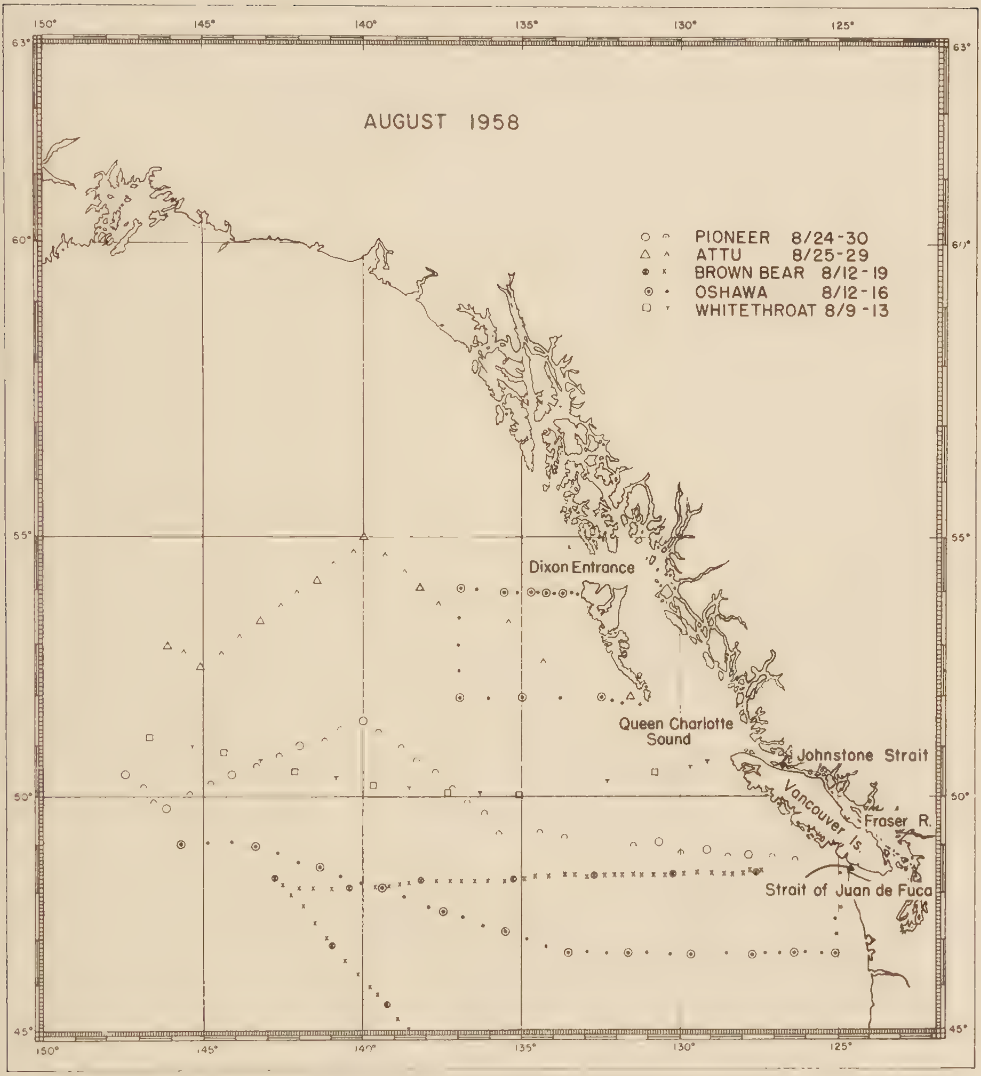

AUGUST 1958
○ ⌒ PIONEER 8/24-30
△ ^ ATTU 8/25-29
⊛ x BROWN BEAR 8/12-19
⊙ • OSHAWA 8/12-16
□ ᵀ WHITETHROAT 8/9-13
Dixon Entrance
Queen Charlotte Sound
Johnstone Strait
Vancouver Is.
Fraser R.
Strait of Juan de Fuca
150°
145°
140°
135°
130°
125°
63°
60°
55°
50°
45°

FIG. 1. Oceanographic and bathythermograph stations, August 1958. (Large symbols indicate oceanographic stations).

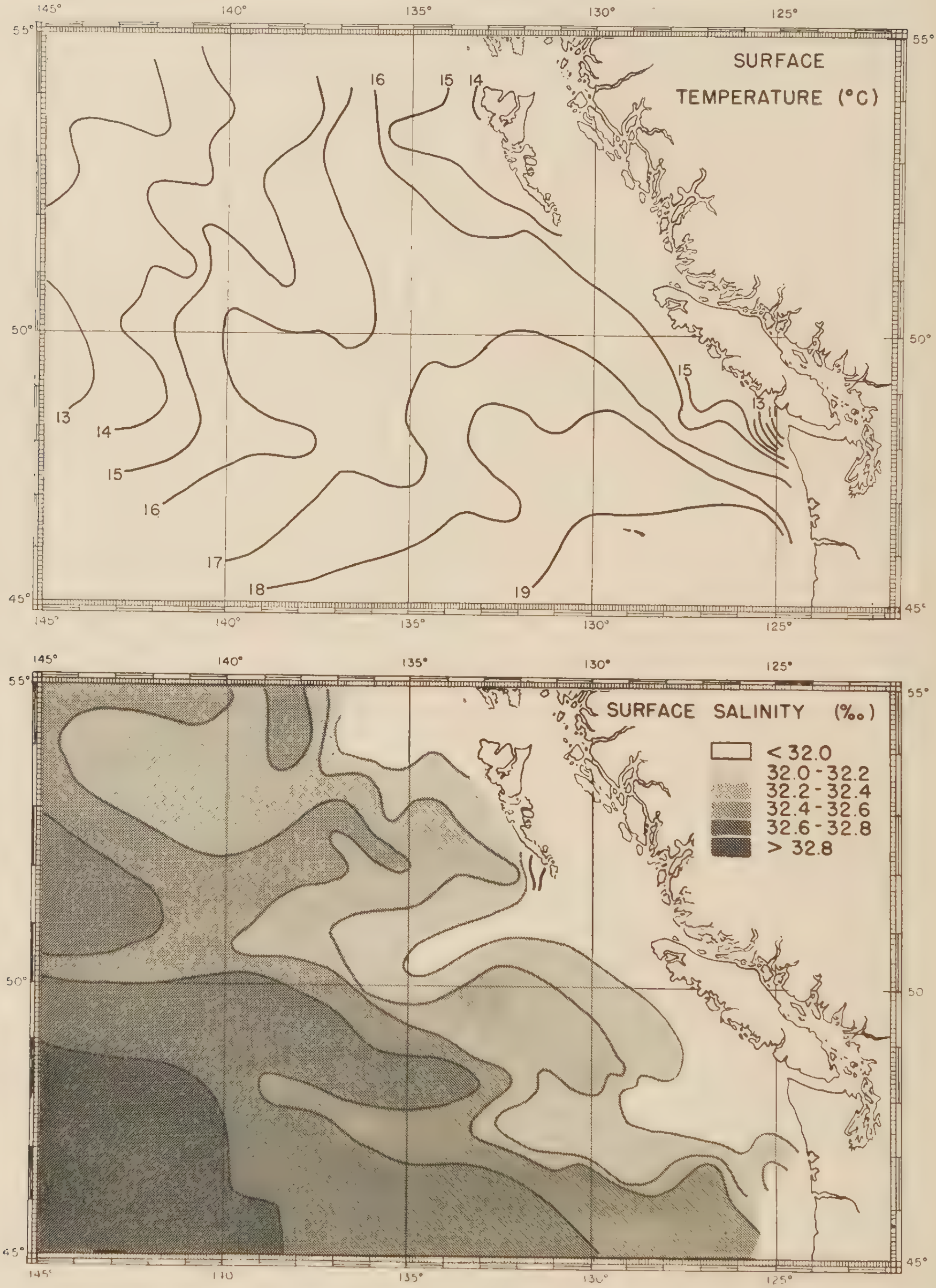

SURFACE
TEMPERATURE (°C)
145°
140°
135°
130°
125°
55°
50°
45°
16
15
14
13
14
15
16
17
18
19
15
13
SURFACE SALINITY (‰)
< 32.0
32.0 - 32.2
32.2 - 32.4
32.4 - 32.6
32.6 - 32.8
> 32.8

FIG. 2. Surface temperature and salinity, August 1958.

SALINITY

The effects of local runoff from the Strait of Juan de Fuca, Queen Charlotte Sound, and Dixon Entrance are immediately apparent as excursions of dilute water into the coastal and offshore regions. These occur as three distinct tongues normal to the coast, and can be identified several hundred miles offshore. The protrusion of the 32.0‰ isohaline off Queen Charlotte Sound extended to Lat. 50°N and Long. 135°W, coinciding with the divergence of the isotherms, as noted above.

SURFACE DATA, 1959

The 1958 data showed that closely spaced observations are necessary to show continuity of the properties in the coastal region. Having been notified of the extensive 1959 summer cruise plans of the Pacific Oceanographic Group (Fisheries Research Board of Canada, 1959), personnel aboard the charter vessels *Pioneer* and *Tordenskjold* made additional observations along Lat. 51 and 53°N in August 1959 while en route to Seattle from the Aleutian area (Favorite *et al.*, 1961). Bad weather prevented taking as many observations as were planned. Figure 3 shows the locations of the surface observations, and the temperature and salinity distributions are shown in Fig. 4.

TEMPERATURE

The surface temperatures in 1959 were generally 2 to 3 C° less than in the previous year, and approximately 1 C° less than the average conditions shown by Robinson (1957). The offshore divergence of the isotherms occurred a little southward and nearer to the coast than in 1958. Even though a marked difference existed in the surface temperatures, the general configuration of the isotherms was similar to that of August 1958. The band of colder temperatures was again present along the coast, and the apparent northward intrusion of warm water was evident approximately 200 miles west of the Washington coast, but did not intrude northward past Vancouver Island as it did during the previous year.

SALINITY

As in August 1958, the local dilution from Queen Charlotte Sound and Dixon Entrance was clearly evident off the coast, but the region of dilute water was confined nearer the coast along a front extending from Lat. 49 to 55°N about 300 miles offshore and approximately parallel to the coastline. Doe (1955) denoted this general area as the separation of the coastal and offshore water masses.

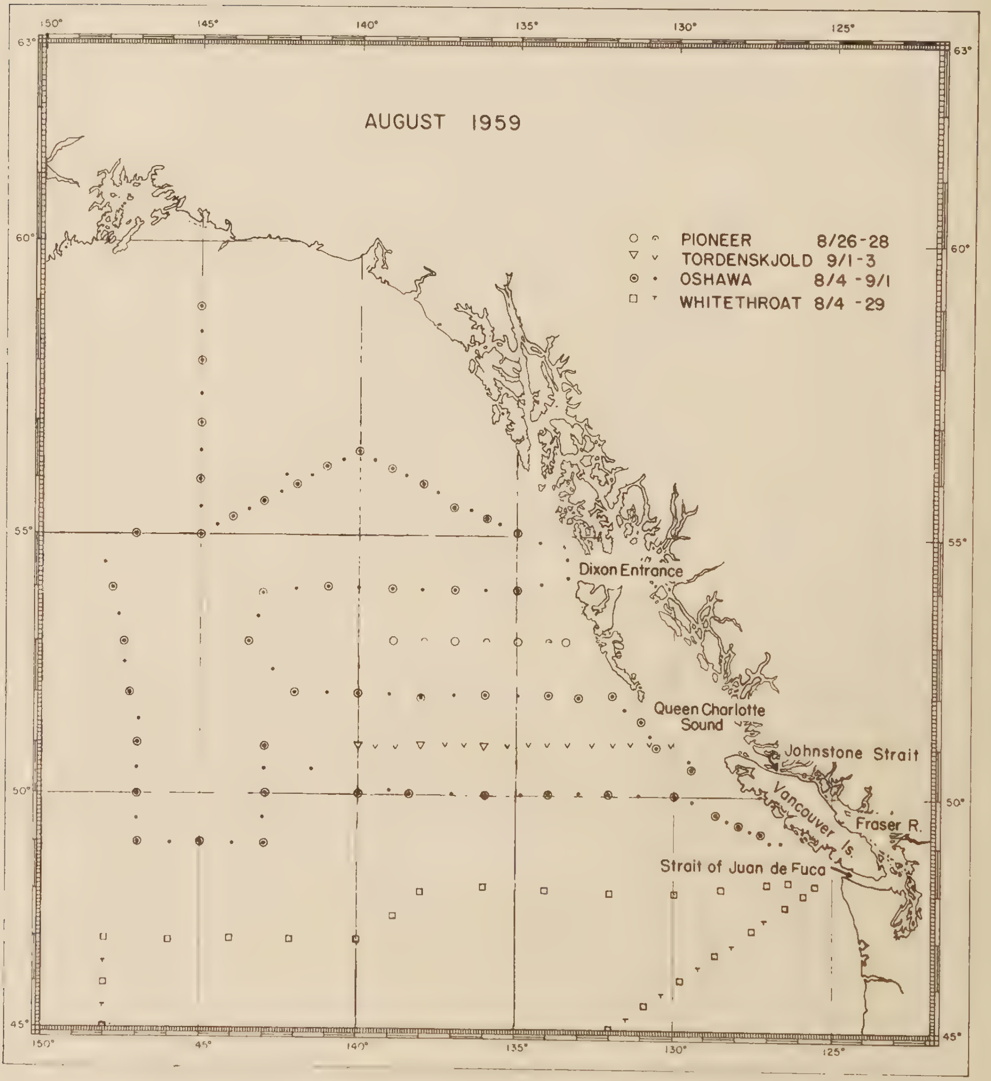

AUGUST 1959
○ ◠ PIONEER 8/26-28
▽ v TORDENSKJOLD 9/1-3
⊙ • OSHAWA 8/4 -9/1
□ ᵀ WHITETHROAT 8/4 -29
Dixon Entrance
Queen Charlotte Sound
Johnstone Strait
Vancouver Is.
Fraser R.
Strait of Juan de Fuca
150°
145°
140°
135°
130°
125°
63°
60°
55°
50°
45°

FIG. 3. Oceanographic and bathythermograph stations, August 1959. (Large symbols indicate oceanographic stations.)

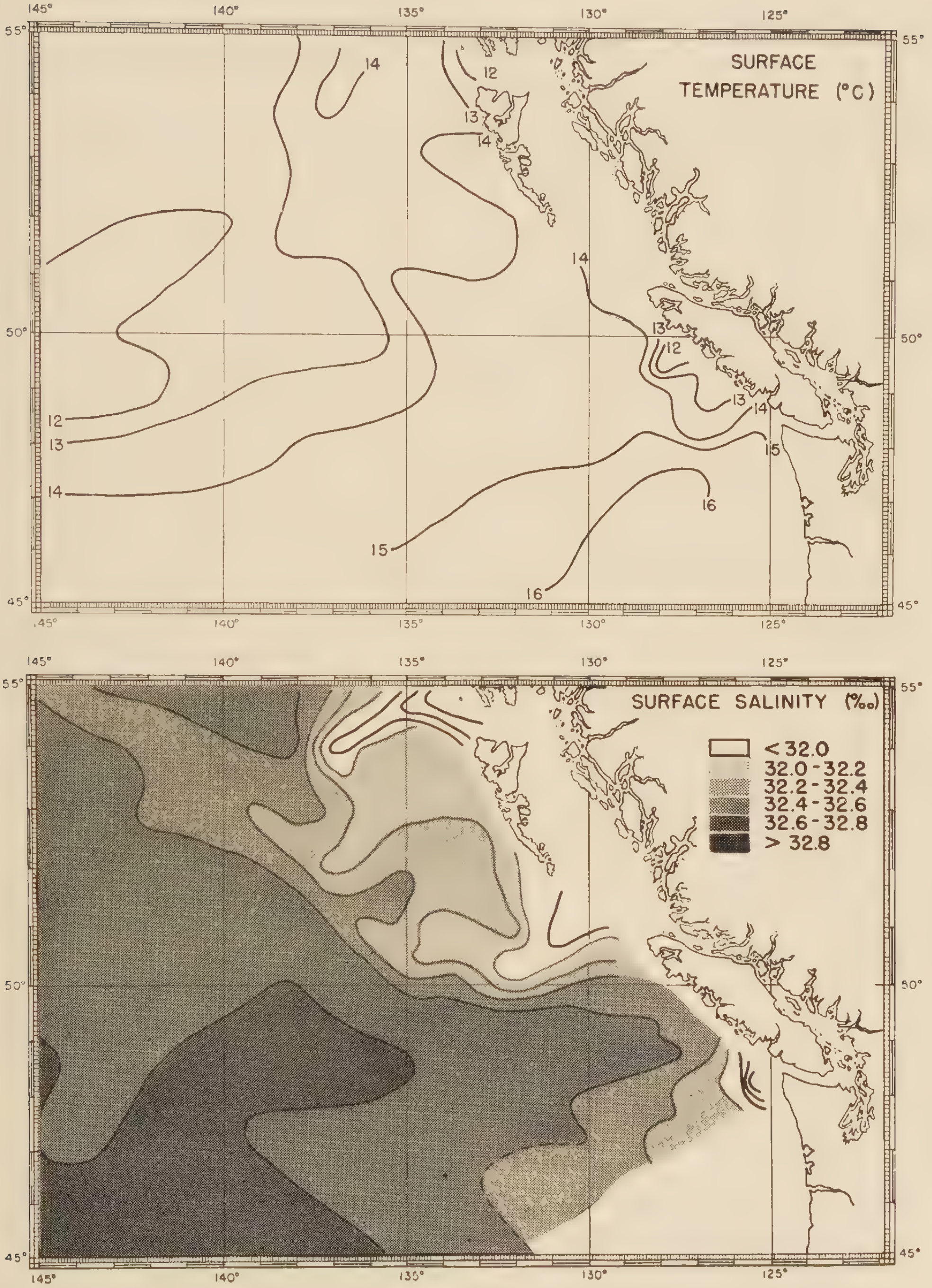

SURFACE
TEMPERATURE (°C)
145°
140°
135°
130°
125°
55°
50°
45°
12
13
14
15
16
SURFACE SALINITY (‰)
< 32.0
32.0 - 32.2
32.2 - 32.4
32.4 - 32.6
32.6 - 32.8
> 32.8

FIG. 4. Surface temperature and salinity, August 1959.

DISCUSSION AND SUMMARY

The coasts of Washington and British Columbia are mountainous, and snow-melt and precipitation draining in spring from an extensive watershed area result in the discharge of considerable amounts of fresh water into the coastal regions. After mixing with sea water in the inshore area, the runoff enters the ocean directly or through various straits or passes. An estimate of how far offshore the properties associated with the runoff may be present, can be ascertained by tracing the seaward extent of the coastal dilution as shown by the surface salinity.

The local runoff from Queen Charlotte Sound in August 1958, as shown in Fig. 2, can be traced across the coastal region into the offshore region, and existed several hundred miles further offshore than shown by previous data cited. Surface temperatures were approximately 1 to 2 C° greater than average. In 1959, although the runoff again was clearly evident offshore, it was confined nearer to the coast than in 1958. Surface temperatures were 2 to 3 C° less than in 1958, and approximately 1 C° less than average.

In both years it is apparent that the surface temperature is not a good indicator of the extent of location of the local runoff during summer. This may possibly be explained by the fact that the cold, snow-melt runoff enters the ocean in late spring; thus subsequent insolation during the summer would result in an equilibrium ocean temperature which prevents any further thermal identity of the water. This gradual warming would tend also to stabilize the layer of dilute water and help to maintain the identity of its salinity values.

In order to ascertain whether the temperature or the salinity more clearly reflected the surface circulation, the dynamic topography of the area was investigated. However, the limited number of stations providing data suitable for permitting this calculation, in contrast to the number of surface observations available, prevents a comparative picture. A similar lack of correlation between the surface temperature and salinity distribution appeared in Doe's work. He compared also the dynamic topography to isentropic charts and discovered that considerable difference in detail existed.

Then too, the excursion of the local runoff, as clearly defined tongues normal to the coast, is interesting because it suggests the absence of any appreciable northerly or southerly current along the coast north of the Strait of Juan de Fuca to Dixon Entrance during the summer months. This is not confirmed by calculations of water transport, and the discrepancy can be resolved only by future direct current measurements.

In attempting to relate surface conditions in the ocean to the migration of salmon, one must be very cautious, because the factors which guide anadromous species to their parent streams after a 1- to 3-year residence in the ocean are not known (Talbot and Sykes, 1958).

The similarity between the location and seaward extent of the local dilution from the British Columbia and Washington coasts in August, 1958 and 1959, and the lack of knowledge concerning the response of salmon to variations in the marine environment, prevent one from making any specific conclusions in regard to the effect of oceanographic conditions on the anomalous migration path of the 1958 Fraser River salmon run. Nevertheless, the extrusions of dilute surface water off the British Columbia coast provide an indication of the location in the ocean where the shoreward-migrating salmon first detect this dilution and may determine the point at which they enter the coastal waters.

REFERENCES

Barnes, Clifford A., and Robert G. Paquette. 1954. Circulation near the Washington coast. *University of Washington, Dept. of Oceanog., Tech. Rept.*, No. 17, 31 pp.

Doe, L. A. E. 1955. Offshore waters of the Canadian Pacific coast. *J. Fish. Res. Bd. Canada*, **12**(1): 1–34.

Favorite, Felix, and Glenn Pedersen. 1959. North Pacific and Bering Sea oceanography, 1958. *U.S. Fish and Wildlife Service, Spec. Scient. Rept.*, Fisheries No. 312, 230 pp.

Favorite, Felix, Richard J. Callaway and James F. Hebard. 1961. North Pacific and Bering Sea oceanography, 1959. *Ibid.*, Fisheries (in press).

Fisheries Research Board of Canada, Pacific Oceanographic Group. MS, 1958a. Physical and chemical data record. North Pacific Surveys, Western Aleutians and Bering Sea, June 27 to August 14, 1958. *MS Rept. Series* (*Oceanog. and Limnol.*), No. 28, 119 pp.

MS, 1958b. Physical and chemical data record. North Pacific Surveys, Continental Shelf and Gulf of Alaska, July 22 to August 16, 1958. *Ibid.*, No. 29, 132 pp.

MS, 1959. Oceanographic data record. North Pacific Surveys, August 4 to September 1, 1959. *Ibid.*, No. 54, 270 pp.

Fleming, Richard H., and staff. 1959. Physical and chemical data, North Pacific Ocean, July to August 1958. *University of Washington, Dept. of Oceanogr., Special Rept.*, No. 30, 191 pp.

International Pacific Salmon Fisheries Commission. 1959. *Ann. Rept.* for 1958, 33 pp.

1960. *Ann. Rept.* for 1959, 40 pp.

Robinson, M. K. 1957. Sea temperature in the Gulf of Alaska and in the Northeast Pacific Ocean, 1941–1952. *Bull. Scripps Institution of Oceanography, U. of California*, **7**(1): 1–98.

Talbot, Gerald, and James E. Sykes. 1958. Atlantic coast migrations of American shad. *U.S. Fish and Wildlife Service, Fishery Bull.*, **58**, No. 142, pp. 473–489.

Tully, J. P. 1937. Report on dynamic studies off the Canadian Pacific coast, 1936. *Trans. American Geophysical Union, 18th Ann. Rept.*, Part 1, pp. 228–231.

Tully, J. P., A. J. Dodimead and S. Tabata. 1960. An anomalous increase of temperature in the ocean off the Pacific Coast of Canada through 1957 and 1958. *J. Fish. Res. Bd. Canada*, **17**(1): 61–80.

Made in United States of America
Reprinted from Limnology and Oceanography
Vol. 6, No. 1, January, 1961
pp. 85–87

MODIFIED VAN DORN WATER SAMPLER

Van Dorn (1957) described a plastic water sampler which is relatively inert chemically, free flushing, and can be messenger activated. He used rubber "force cups" for closures, commonly known as "plumber's friends." We have devised a sampler of similar design but with improved rubber ball closures that eliminate malfunctions due to improper seating of the force cup closures. This sampler consists of Plexiglas tubes, 20 in. long with an outside diameter of 4.5 in. and a capacity of approximately 4 L (Fig. 1).

For van Dorn's closures we substituted 4.5-in. rubber balls, molded from gum rubber with ¼-in. holes through the center. Neoprene or other similar lighter weight derivatives would be preferable if available. The most desirable feature of these ball closures is that they remain completely spherical after repeated use and form a perfect seal with the rims of the plastic sampling container. For a better fit and less wear on the surgical rubber tubing connecting them, the inside rim of this sampler was machined to a 30° bevel and the outer rim sanded. The balls were connected to the rubber tubing as follows: one end of each ball hole was countersunk for ½ in. to a diameter of 9/16 in. The head of a 5-in. ¼-20 brass bolt was inserted ½ in. into the end of a 10-in. piece of 5/16 × 3/32-in. surgical rubber tubing and held by a ligature of nylon thread. The bolt was passed through the ball hole and secured by a nut after a 1-in. micarta washer was first placed over the threaded bolt. By tightening the nut, the end of the rubber tubing was forced back against the walls of the countersunk 9/16-in. hole to form a tight non-metallic seal. Loops of Steelon wire were fastened to the upper part of the closures and inserted in the "U" head of the tripping rod in the cocked (pretripped) position (Fig. 2). The ball closures were then outside the sampling container and permitted complete flushing. For more durability

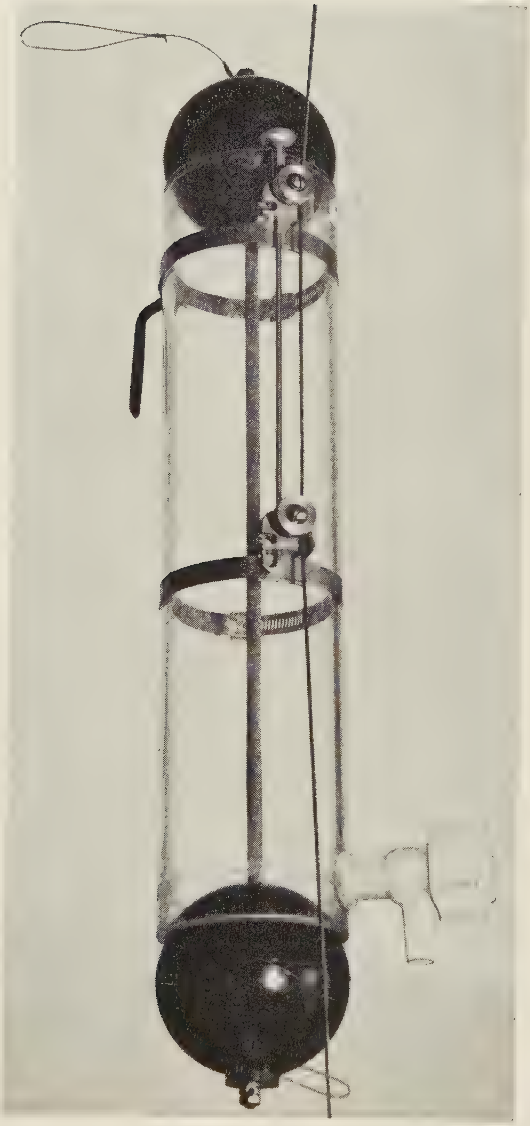


FIG. 1. Four-liter water sampler in closed position showing the attachment and tripping assemblies. Ball closures are held in place by tension of surgical rubber tubing.

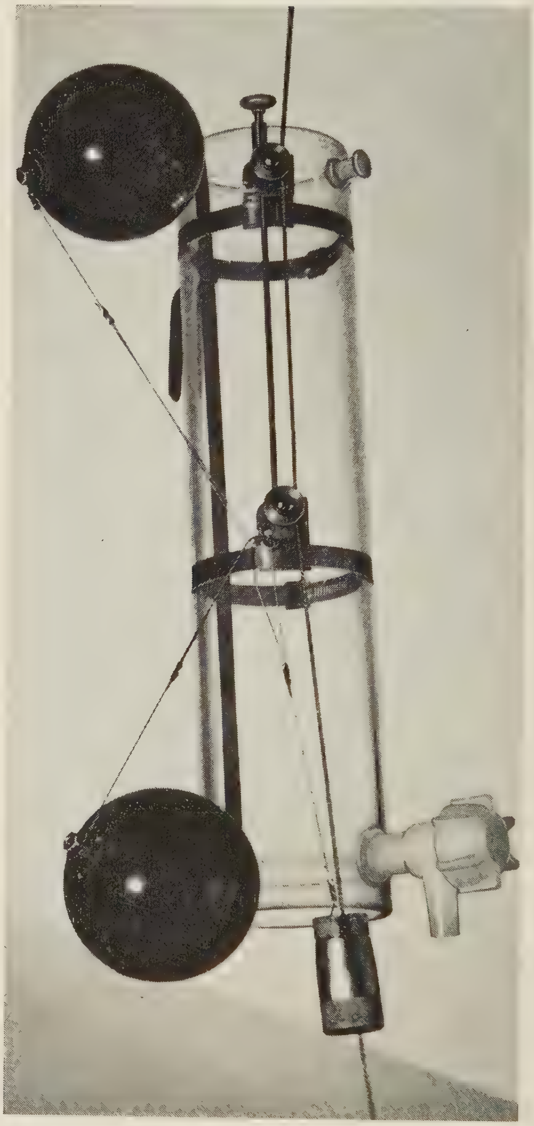


FIG. 2. Four-liter water sampler in a pretripped position showing wire loops from closures inserted in "U" bend of tripping rod and messenger attachment.

the sampling container can be made from polyvinyl chloride instead of the acrylic resin (Plexiglas) tubing used by van Dorn. Although polyvinyl chloride is extremely resistant to cracking and breakage, it is opaque, making it impossible to view the water level through the walls of the sampling container. Both plastics can be sawed and machined easily. We used Nalgene[1] ½-in. threaded spigots with a Teflon "O" ring for draining and ¼-in. Nalgene plugs for venting our samplers. These proved more efficient in operation than latex hose equipped with pinchcocks. When available, stainless steel bolts and nuts can be used instead of brass.

---

[1] The Nalge Company Inc., Rochester 2, New York.

To attach these water samplers to the hydrographic wire, specially designed attachment and release assemblies were made for us by the Hytech Corporation.[2] These units consist of two cadmium plated irradiated brass castings provided with knurled stainless steel knobs, which tighten directly on the cable. This clamp can be used with any hydrographic cable between 3/32- and 7/32-in. diameter. A stainless steel ¼-in. tripping rod with cadmium plated button and "U" head comprises the release assembly. This rod is 9 in. long from center to center of the clamp castings. The lower clamp assembly was used for both the release of the messenger as well as the wires for the closing valves. These attachment units provide stability on longer bottles and aid in supporting the weight of larger samplers. Two aeroseal stainless steel hose clamps were used to fasten the attachment and release units to the samplers. For rack storage a handle was riveted to the upper aeroseal clamp.

These sample bottles are inexpensive to construct and permit multiple water samples to be made on one hydrographic cast. They are especially suitable for shallow water operation, where incomplete flushing of Nansen or similar water samplers may occur. Furthermore, the large capacity of the unit provides ample water for chemical and biological analysis.

John H. Finucane and
Billie Z. May

Galveston Biological Laboratory
U. S. Bureau of Commercial Fisheries
Galveston, Texas

REFERENCES

Van Dorn, W. G. 1957. Large-volume water sampler. Trans. Amer. Geophys. Union, **37:** 682–684.

---

[2] Hytech Corporation, 6803 West Boulevard, Inglewood 3, California.

36

GROWTH IN THE STELLER SEA LION

CLIFFORD H. FISCUS

Reprinted from JOURNAL OF MAMMALOGY
Vol. 42, No. 2, 20 May 1961
pp. 218–223
Made in United States of America

Made in United States of America
Reprinted from Journal of Mammalogy
Vol. 42, No. 2, 20 May 1961
pp. 218–223

GROWTH IN THE STELLER SEA LION

Clifford H. Fiscus

GROWTH IN THE STELLER SEA LION

By Clifford H. Fiscus

ABSTRACT: A discontinuity (growth line) is formed annually in dentin and cementum of the teeth of *Eumetopias jubata*. In a sample of 59 individuals, the oldest male showed 19 growth lines, the oldest female 22. Maximum body length and girth were, for males, 325 and 229 cm, for females, 269 and 168 cm. On the evidence of 12 skull measurements, the growth rate tends to level off at about 8 years in females and 10 years in males. The basioccipital–basisphenoid suture closes at about age 4 in both sexes. A sagittal crest is strongly developed in the male. Baculum length and weight tend to increase with age; the largest specimen (length 196 mm, weight 55 g) was from a 16-year-old. Of 28 bacula, one had been broken and was partly knit. Of 49 skulls, 6 lacked (from birth) 1 or 2 molariform teeth.

Skulls of the Steller sea lion, together with body length and girth measurements, were received by the Marine Mammal Biological Laboratory in November 1959 from Dr. Ole A. Mathisen, Fisheries Research Institute, University of Washington. The collection was made in June and July of 1958 at Chernabura Island (Shumagin group), Alaska (Mathisen, 1959) as part of a sea-lion investigation made through a contract with the Bureau of Commercial Fisheries.

The collection consisted of 49 skulls, of which 28 were taken from males and 21 from females; and the canine teeth from 5 other males and 5 other females. Date of collection and length and girth were missing from 10 of the specimens.

The purpose of this paper is to indicate the rate of growth, by sex, for certain skull characters, body length and girth, and baculum length and weight.

METHODS

Age-determination techniques used here were those originally developed for use on fur seals (*Callorhinus ursinus*) by Scheffer (1950). Further refinements in preparation of *Callorhinus* teeth for age-determination purposes have been described by Wilke *et al.* (1958). Essentially, the upper right canine tooth was removed, sectioned, and examined under a 3× lens. Annual growth was revealed in most teeth by cutting them in half longitudinally. Thin, longitudinal sections were taken from the center of teeth that were especially large or difficult to read, in order to improve growth-line visibility by permitting greater light penetration.

Structural growth of the sea-lion tooth is similar to that of the fur seal. The pulp chamber of the female tooth is well filled by 11 or 12 years and almost completely closed by 15 or 16 years. Closure is slower in the male. At 15 or 16 years, the pulp cavity of the male tooth is relatively larger than in a female tooth of the same age but is closed to a greater degree than in the female tooth of 11 or 12 years. The cementum layer contains annual growth lines which correspond to those of the dentin. Where the growth lines become obscure in the detin, the age can sometimes be determined on the cementum. The cementum layer in young teeth is usually not thick enough for age-determination techniques to reveal the annual lines clearly.

TABLE 1.—*Age and sex variation in body length and girth (cm) and 12 selected skull characters (mm)*

Age	N*	BL	G	CBL	BLH	PL	ZW	MW
Male:								
pup	1	–	–	201	–	–	–	–
1	1	178	114	249	226	109	131	114
3	2	208	143	307	274	145	159	136
5	1	272	178	361	329	171	196	183
7	1	262	178	343	312	168	194	173
8	2	310	229(1)	369	339	183	209	196
9	4	288	188	358	330	177	212	191
10	3	301(2)	188(2)	363	333	179	214	197
11	3	295	202	381	346	188	221	215
12	4	299	191	371	341	187	220	205
13	1	–	–	376	346	189	234	213
15	2	317(3)	210(3)	382	348	194	222	206
16	2	325	199	389	358	197	230	224
19	1	317	185	396	366	201	247	239
Female:								
2	1	180	117	252	225	111	135	114
9	2	237	160	303	277	144	162	141
10	2	234	152	309	281	151	169	151
11	2	237	154	300	274	137	163	144
12	3	243(2)	155(2)	303	278	147	161	144
13	2	243	171	307	282(1)	145	165	147
14	3	250	149	309	285(2)	150	167	150
15	1	244	147	320	294	152	168	153
16	1	252	157	315	285	149	171	149
17	1	264	168	315	285	150	177	146
18	2	245	155	306	278	145	171	155
19	1	236	155	–	–	–	–	–
20	1	269	163	322	297	154	171	156
22	1	241	165	–	–	–	–	–

Age	N*	IOW	LN	WN	H	UMS	MG	SW
Male:								
pup	1	60	32	24	–	55	4	67
1	1	51	31	27	102	69	8	73
3	2	51	47	33	110	84	17	90
5	1	56	67	40	123	100	24	111
7	1	52	51	40	124	97	22	104
8	2	55	57	48	143	101	24	121
9	4	56	54	41	138	102	24	121
10	3	61	57(2)	45(2)	144	103	25	124
11	3	56	59	43	151	109	26	125
12	4	57	59	43	147	101	21	125
13	1	56	58	46	159	108	27	130
15	2	57	59	45	153	111	23	121
16	2	62	65	47	165	111	29	143
19	1	60	62	49	160	104	22	136

TABLE 1.—continued

Age	N*	IOW	LN	WN	H	UMS	MG	SW
Female:								
2	1	46	38	–	96	67	8	66
9	2	47	43	31	107	89	21	83
10	2	49	47	33	112	91	21	91
11	2	41	47	29	107	86	21	78
12	3	44	46	31	108	90	21	84
13	2	49	50	31	109	91	25	85
14	3	45	45	34	109	93	23	86
15	1	45	47	31	116	94	23	88
16	1	47	48	35	111	–	–	86
17	1	44	46	36	109	94	21	77
18	2	48	43	31	109	88	19	82
19	1	–	–	–	–	–	–	–
20	1	43	46	32	116	96	20	80
22	1	–	–	–	–	–	–	–

* Number of specimens. Where more than one was available, the mean measurements are given. A number in parentheses ( ) indicates a different number of specimens.

The growth lines appear in the dentin as a series of alternating dark (winter growth) and light (summer growth) layers. A narrow layer or band is formed at birth. This is either translucent or opaque and is distinct from adjacent layers. It can be observed externally as a slight ridge encircling the tooth. Inasmuch as the ridges are visible extensions of the annuli, they are valuable as a check against internal layers in younger teeth. In older animals, the ridges become obscure and cannot be relied upon. One dark and one translucent layer represent one year of growth. Since the present specimens were collected in summer, a light band was being formed on the wall of the pulp chamber. Caniniform incisors (upper I^3) of four male specimens were also prepared. Growth lines on three pairs of incisors were found to correspond in number to those on the canines; growth lines on one pair were not distinct. No teeth of known-age sea lions were available for comparison but it is the author's opinion, based on experience with fur-seal teeth of known age, that the age-determination technique is accurate within plus-or-minus one year for most of the sea-lion specimens. Greater accuracy is attained in younger than in older specimens.

Eighteen abbreviations are used in Tables 1 to 3. Some of them refer to measurements, others to anatomical parts. The measurements are essentially those of Grinnell *et al.* (1937) and of Hall (1946). A key follows: *BL*, body length; *BLH*, basilar length of Hensel; *CBL*, condylobasal length (= entire length of skull in the sea lion); *G*, girth (behind fore flippers); *H*, height of skull at otic bullae; *I*, incisor; *IOW*, interorbital width (least distance across top of skull between orbits); *LN*, length of nasals; *M*, molar; *MG*, molar gap (diastema between sockets of upper P^4 and M^1); *MW*, mastoid width (exceeds width of brain case in sea lions 3 years old or older); *N*, number of specimens; *P*, premolar; *PL*, palatilar length; *SW*, supraorbital width (between supraorbital processes); *UMS*, alveolar length of upper molar series; *WN*, width of nasals (greatest); *ZW*, zygomatic width.

RESULTS

Skull measurements are summarized by age and sex in Table 1. Where more than one individual of the same age and sex is represented, the mean is given.

Growth is rapid in the younger year-classes. The 1-year-old male approaches the size of the 2-year-old female in both body length and condylobasal length. In fact, sexual dimorphism is apparent in most skull characters. About 90 per

TABLE 2.—*Size of body and skull, according to age and as percentage of adult size**

Age	BL, cm	% adult length	CBL, mm	% adult length	MW, mm	% adult width	H, mm	% adult height
Male:								
1	178	55.6	249	64.3	114	52.1	102	64.2
3	208	65.1	307	79.3	136	62.1	110	69.2
5	272	84.9	361	93.3	183	83.6	123	77.4
7	262	81.8	343	88.6	173	79.0	124	78.0
8	310	96.8	369	95.3	196	89.5	143	89.9
9	288	89.9	358	92.5	191	87.2	138	86.8
10	301	94.1	363	93.8	197	90.0	144	90.6
11	295	92.3	381	98.4	215	98.2	151	95.0
12	299	93.3	371	95.9	205	93.6	147	92.5
13	–	–	376	97.2	213	97.3	159	100.0
15	317	99.2	382	98.7	206	94.1	153	96.2
16	325	101.6	389	100.5	224	102.3	165	103.8
19	317	99.2	396	102.3	239	109.1	160	100.6
	(320)*		(387)*		(219)*		(159)*	
Female:								
2	180	72.2	252	80.3	114	75.0	96	85.7
9	237	95.2	303	96.5	141	92.8	107	95.5
10	234	93.6	309	98.4	151	99.3	112	100.0
11	237	95.1	300	95.5	144	94.7	107	95.5
12	243	97.2	303	96.5	144	94.7	108	96.4
13	243	97.2	307	97.8	147	96.7	109	97.3
14	250	100.1	309	98.4	150	98.7	109	97.3
15	244	97.7	320	101.9	153	100.7	116	103.6
16	252	100.8	315	100.3	149	98.0	111	99.1
17	264	105.8	315	100.3	146	96.1	109	97.3
18	245	98.3	306	97.5	155	102.0	109	97.3
19	236	94.6	–	–	–	–	–	–
20	269	107.9	322	102.5	156	102.6	116	103.6
22	241	96.7	–	–	–	–	–	–
	(250)*		(314)*		(152)*		(112)*	

* Adult measurements are the means for animals 15 years old or older.

cent of adult body length is achieved by age 8 to 10 (Table 2). Young animals of both sexes are poorly represented in the sample; therefore, the age limit for rapid growth is not exact. Measurements of condylobasal length, basilar length, palatilar length, zygomatic width, mastoid width, length of nasals, width of nasals, height of skull at otic bullae, and alveolar length of upper molar series show growth characteristics similar to body length.

Interorbital width differs between males and females, though it appears to change little with age.

Sexual dimorphism is least apparent in the measurement of molar gap; however, the growth rate is similar to that of the condylobasal length.

Height of the sagittal crest (not given in the table) increases as the animal grows older. Sagittal-crest height in males 7 years of age and older ranges from 7 to 37 mm. In females 9 years old and older, sagittal-crest height ranges from 2 to 7 mm, except for a 13-year-old skull on which no crest is evident.

The degree of suture closure between the basioccipital and basisphenoid bones was checked as an indicator of age. The suture is open in the male pup and 1-year-old male, and in the 2-year-old female. It is partly closed in the two 3-year-old males. In male skulls age 5 and older and in female skulls age 9 and older, it is closed.

Damaged teeth and alveoli occurred frequently and in about equal proportions among males and females. Except for the missing alveoli shown for various skulls in Table 3, dentition is otherwise normal.

TABLE 3.—*Missing and damaged alveoli in nine skulls*

Age	Skull No.	Sex	Missing alveolus	Remarks
9	57	♂	left M^1	congenital
			right M_1	congenital
11	21	♂	left M^1	congenital
15	53	♂	left M^1	congenital
16	1	♂	right P^2	congenital ?
19	40	♂	right M^1	acquired—early damage
10	47	♀	left I_2	acquired—early damage
11	48	♀	right M_2	congenital ?
14	14	♀	right M^4	congenital
16	29	♀	right and left M^1	congenital

Measurements and weights of 29 bacula (not given in the table) showed a rapid growth to age 7 to 9, increasing only slightly thereafter. Weight data are not completely reliable because methods of cleaning the bacula varied. The largest baculum (196 mm, weight 54.6 g) was from a 16-year-old. The only instance of damage was observed in the broken and partially knit baculum of a 19-year-old animal.

ACKNOWLEDGMENTS

The author is indebted to Ole A. Mathisen of the Fisheries Research Institute for making the material and data available; to Thomas P. O'Brien for assistance in preparing, measuring, and reading the age of the material; to Victor B. Scheffer for his assistance with the manuscript; and to other staff members of the Marine Mammal Biological Laboratory for critical comments.

LITERATURE CITED

GRINNELL, J., J. S. DIXON AND J. M. LINSDALE. 1937. Fur-bearing mammals of California. Berkeley, Univ. Calif. Press, 2 vols.

HALL, E. R. 1946. Mammals of Nevada. Berkeley, Univ. Calif. Press, 710 pp.

MATHISEN, O. A. 1959. Studies on Steller sea lion (*Eumetopias jubata*) in Alaska. Trans. N. Am. Wildlife Conf., 24: 346–356.

SCHEFFER, V. B. 1950. Growth layers on the teeth of Pinnipedia as an indication of age. Science, 112: 309–311.

WILKE, F., K. NIGGOL AND C. H. FISCUS. 1958. Pelagic fur seal investigations, California, Oregon, Washington and Alaska. Unpubl. report, Bureau of Commercial Fisheries, Seattle; 96 pp.

U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Seattle, Washington.
Received 20 September 1960.

37

Size Distribution by Depth of the Longfin Hake, *Phycis chesteri*

Raymond L. Fritz

Reprinted from COPEIA, 1961, No. 2, pp. 229-230, June 19
Printed in U.S.A.

Reprinted from COPEIA, 1961, No. 2, pp. 229–230, June 19
Printed in U. S. A.

SIZE DISTRIBUTION BY DEPTH OF THE LONGFIN HAKE, *PHYCIS CHESTERI*.—The longfin hake, *Phycis chesteri* Goode and Bean, is one of the many species of hakes inhabiting the waters off the Atlantic coast of the Untied States. Because of its deep-water habits, very little is known about the biology and general habits of this species. Bigelow and Schroeder (1953, *U. S. Fish. Wildl. Serv. Fish. Bull. 53:232*) report it to be abundant on the slope of the continental slope of North America from the Laurentian Channel in Cabot Strait to abreast of Cape Lookout, North Carolina. Bigelow and Schroeder (1936, *Bull. U. S. Bur. Fish. 48(20):339*) and Schroeder (1955, *Deep Sea Res. 3(suppl.):358–72*) defined the depth distribution of the longfin hake in the Gulf of Maine as being from 70 to 140 fathoms and along the continental slope from 200 to 450 fathoms. W. C. Schroeder (personal communication) of the Woods Hole Oceanographic Institution caught *P. chesteri* as deep as 720 fathoms on an exploratory cruise in 1953. None of these reports includes length frequencies.

TABLE 1.—SIZE DISTRIBUTION BY DEPTH OF THE LONGFIN HAKE, *Phycis chesteri*.

Date	August 1959					Dec. 1959		Feb. 1960	
Depth (fathoms)	100–200	200–300	300–400	400–500	500–600	100–200	200–300	100 200	200–300
Fish length (cm.)									
9	—	—	—	—	—	—			—
10	2	*	—	—	—	—	—	—	2
11	4			—					
12	2		—	—	—	—	—		
13	1		—	—	—	—	—	—	—
14	1		—	—	—	—	—	—	—
15	9		—	—	—	—	—	—	
16	23		—	—	—	—	—	—	3
17	29		—	—	—	—	—	—	4
18	45		—	—	—	1	1	—	19
19	42		—	—	—	—	1	—	14
20	32		—	—	—	—	2	—	15
21	14		—	—	—	—	3	—	34
22	2		—	—	—	—	—	—	40
23	1		—	—	—	—	1	—	37
24	1		—	2	—	—	—	—	19
25	1		—	—	—	—	—	—	11
26	3		—	1	—	1	—	—	15
27	1		1	6	—	1	—	—	10
28	3		—	1	—	—	—	—	14
29	—		2	2	—	1	3	—	16
30	2		3	3	—	1	—	—	22
31	1		2	2	—	—	1	—	18
32	1		2	6	—	—	1	—	18
33	—		1	12	—	—	1	—	8
34	—		4	18	—	—	—	—	10
35	—		5	23	—	—	—	—	4
36	—		—	22	1	—	—	—	6
37	—		—	14	—	—	—	—	3
38	—		2	12	—	—	—		—
39	—		—	10	1	—	—	—	—
40	—		—	2	—	—	—	1	
41	—		—	1	—	—	—	—	—
42	—		—	1	—	—	—		
No of fish	220		22	101	2	5	14	1	342
Mean length	18.5		32.7	34.3	37.5	26.0	24.7	—	25.1

*No sample.

Recent cruises conducted by the Bureau of Commercial Fisheries in August and December 1959 and February 1960 have added information on the distribution of the longfin hake. In August 1959, we made otter trawl tows at each 100-fathom depth from 100 to 1000 fathoms along the continental slope off Block Island, Rhode Island (Lat. 40° 00′ N. – Long. 70° 59′ W. to Lat. 39° 46′ N. – Long. 71° 27′ W.). Due to the uneven bottom, it was not possible to tow exactly along a prescribed isobath. The gear was, therefore, towed in those areas where the range in depth over the distance of a tow did not exceed 100 fathoms. The data indicate that the longfin hake were distributed by size according to depth. The length frequency distribution of *P. chesteri* by depth is presented in Table 1.

It can be seen that, in August 1959, hake from 10 to 32 cm. in length (mean length 18.5 cm.) were found at the 100- to 200-fathom depth.

Larger hake ranging from 27 to 38 cm. in length, with a mean length of 32.7 cm. were found in 300 to 400 fathoms. The range in length for the hake caught between 400 and 500 fathoms was from 24 to 42 cm. with a mean length of 34.8 cm. The catch for the depth between 500 and 600 fathoms contained only two fish which measured 36 and 39 cm. in length. No longfin hake were caught in depths greater than 600 fathoms.

In December 1959 and February 1960, we fished from 20 to 300 fathoms in the same general area. The gear on these cruises was not rigged to fish deeper than 300 fathoms so no direct comparisons are possible. The largest number (356) of hake were caught between 200 and 300 fathoms as compared with the tows made in the 100-fathom depth, where only six hake were caught. The length frequencies from these cruises are included in Table 1, to show the size distribution for the 200- to 300-fathom depth. The longfin hake taken on these cruises ranged from 16 to 37 cm. in length, with a mean length of 25.4 cm.

From these data, it can be seen that longfin hake tend to be distributed by size according to depth along the continental slope. The largest longfin hake measured 42 cm. and was taken between 400 and 500 fathoms.—RAYMOND L. FRITZ, *U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts.*

Reprinted from PROCEEDINGS OF THE NATIONAL SHELLFISHERIES ASSOCIATION, Volume 51, 1960

38

THE THREE HEARTS OF THE OYSTER

Paul S. Galtsoff

Department of the Interior
U. S. Fish and Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory, Woods Hole, Massachusetts

ABSTRACT

Circulation of blood in the oyster is impeded by large and open sinuses between the arteries and veins. This deficiency is compensated by the pulsating radial vessels of the mantle and by the two accessory hearts in the cloacal wall. Each accessory heart consists of three branches emerging from a common center. Two distinct waves of contraction originate from the center and move in opposite directions. Injections of dyes shows that blood from the accessory hearts enters the circumpallial artery and the efferent veins of the gills. The function of the accessory hearts is to oscillate the blood in the pallial sinuses; their contractions are slow and independent of the beating of the principal heart.

Blood circulation in lamellibranch mollusks is a mechanical puzzle. Instead of having capillaries as in higher forms, the arteries and veins of lamellibranchs are connected through sinuses or lacunae which are merely slits in the connective tissue and have no walls. The sinuses are periodically filled with blood cells which wander freely among the organs and aggregate in large numbers on the surface of the body. The veins which start from the sinuses carry blood through the common afferent vein to the gills, and then return it to the heart by a complex of efferent branchial vessels. It is difficult, however, to visualize how the circulation is maintained in a system whose continuity is interrupted by wide and irregular open spaces.

This deficiency is compensated by the contractions of the gills and of the adductor muscle. Their muscular movements compress the tissues, squeeze the blood from the sinuses and force it into the veins. The flow of the blood inside the mantle is aided by the pulsation of the vessels along the radial muscles. These vessels have poorly developed walls. Their constriction produces a wave of contraction which originates at the base of the mantle and progresses toward its periphery where the radial vessels branch off and establish connection with the circumpallial artery. Pulsation of these vessels and the oscillation of blood inside them may be observed in a fully expanded mantle. On the surface of the mantle the radial vessels and the accompanying muscles appear as ridges, which were noted by Rawitz (1888) and described by Kellogg (1890).

The principal organs for oscillation are, however, the two vessels on the lateral walls of the cloacal chamber. They were found by Hopkins (1934, 1936) and Elsey (1935) in three species of edible oysters, Crassostrea gigas, C. virginica, and Ostrea edulis. Hopkins, who suggested the name "accessory hearts," described them as prominent, tubular vessels located between the ventral margin of the mantle at one end and the excretory organ on the other.

Under slight mechanical stimulation the delicate walls of accessory hearts collapse and the structures become invisible. This explains the failure of earlier investigators to recognize their existence. For the same reason the injection of accessory hearts with dyes or latex is difficult and can be accomplished only in a well narcotized and relaxed oyster.

The following method of injection proved satisfactory. Live oysters were kept for 24-48 hours in a refrigerator, then placed overnight in cold sea water with 5 per cent magnesium sulphate. About 2 ml of lithium carmine was injected using the finest hypodermic needle. The preparation was rapidly rinsed in fresh water and immediately immersed in 95 per cent ethanol which precipitated the dye. The injected material remained inside the vessels and was not diffused or washed away by dehydration or by clarifying agents (cedar oil or xylene). In this way several permanent preparations were obtained.

The accessory heart of Crassostrea virginica is not a simple tubular structure as has been described by Hopkins. It consists of three branches of almost equal size, joined together at the common center (Fig. 1). The entire structure is shaped like the letter Y. The lower or ventral branch (v. br.) extends along the wall of the cloaca to the pallio-branchial junction (p. br. j.). Dye injected into this branch penetrates some distance into the circumpallial arteries of the right and left mantle lobes and into the side vessels which join the small branches of the efferent vein of the gills (ef. v.). The dorsal branch (d. br.) continues along the wall of the cloaca. It does not "disappear into the excretory organs," as stated by Hopkins, but extends under the renal sinus (r. s.) to the dorsal part of the cloacal wall. The ramifications of the branch end in a number of capillaries which connect them with the efferent vein. The third, i.e., the posterior branch (p. br.) follows the ventro-lateral border of the adductor muscle and gives many ramifications inside the cloacal wall. The histology of the

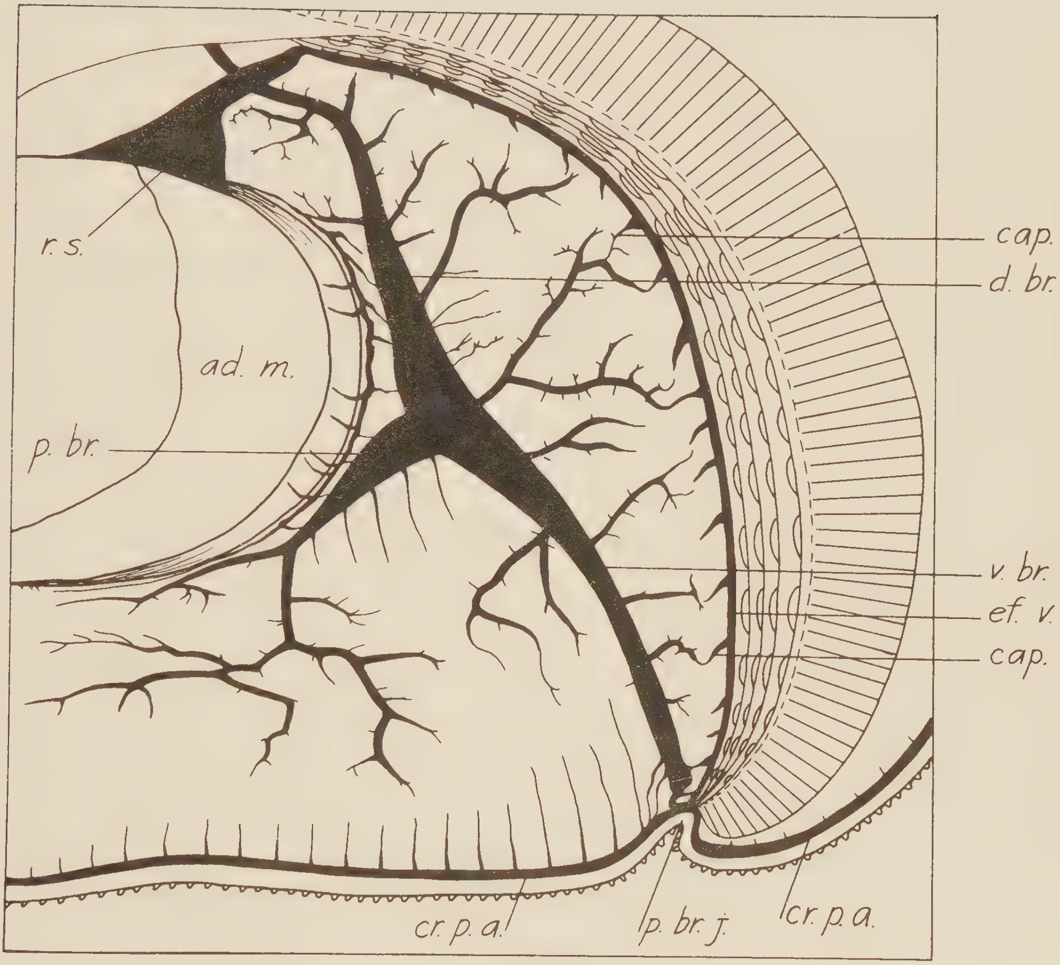

r.s.
ad. m.
p. br.
cap.
d. br.
v. br.
ef. v.
cap.
cr. p. a.
p. br. j.
cr. p. a.

Fig. 1. Drawing of the accessory heart of the oyster, Crassostrea virginica. Made from an injected preparation. ad.m.--adductor muscle; cap.--capillaries; cr.p.a.--circumpallial artery; d.br.--dorsal branch of the accessory heart; p.br.--posterior branch of the accessory heart; v.br. --ventral branch of the accessory heart; r.s.--renal sinus.

accessory heart can be studied only in a fully relaxed organ. The cross section shows a delicate endothelial lining consisting of small elongated cells, and a muscular membrane of thin circular and scattered longitudinal muscle fibers. In a contracted state the heart completely collapses and these features become almost unrecognizable.

The pulsation of the accessory heart is interesting. Two waves of contractions originate at the central part of the heart and move in opposite directions. One wave proceeds from the point of origin at the center toward the distal end of the dorsal branch; the second wave also arises at the common center but progresses along the ventral branch toward the pallio-branchial junction. No contractions were detected in the third, posterior branch.

The rate of the contractions of the accessory hearts is 6-7 times per minute at room temperature. The transmission of the impulse is slow, varying from 3 to 8 mm per second. The movements are not well coordinated and are independent of the beating of the principal heart which contracts at the rate of 16-18 times per minute. By dissecting the wall of the cloaca and removing the pericardium the beating of the principal heart and of one accessory heart can be observed simultaneously. The accessory heart on the other side of the oyster is not visible in such preparations and consequently, it is not known whether the contraction of the pair is coordinated.

Blood carried by the ventral branch of the accessory heart enters the pallial artery against the pressure produced by the principal heart. Under these conditions the penetration of blood inside the artery must be limited; by the end of the contraction wave some of the blood probably returns to the accessory heart. Movement of the blood inside the pallial artery can not be seen but back and forth flushing of blood cells can be observed through the thin wall of the accessory heart.

Ramifications of the ventral and dorsal branches of the accessory heart provide connections with the side vessels of the efferent veins. It can be assumed from the direction of the contraction waves that blood from the accessory heart moves toward the efferent vein of the gill, and that part of this blood is flushed back as the impulse wave progresses along the wall of the branch.

Oscillation of the blood in the mantle is the primary function of the accessory hearts. They facilitate the gaseous exchange and provide means for efficient respiration. The location of the accessory heart confirms the opinion that the mantle and the wall of the cloaca play significant roles in the respiration of oysters.

LITERATURE CITED

Elsey, C. R. 1935. On the structure and function of the mantle and gill of Ostrea gigas (Thunberg) and Ostrea lurida (Carpenter). Trans. Roy. Soc. Canada, Sec. V (1935): 131-160.

Hopkins, A. E. 1934. Accessory hearts in the oyster, Ostrea gigas. Biol. Bull. 62: 346-355.

Hopkins, A. E. 1936. Pulsation of blood vessels in oysters, Ostrea lurida and O. gigas. Biol. Bull. 70: 413-425.

Kellogg, J. L. 1890. A contribution to our knowledge of the morphology of lamellibranchiate mollusks. U. S. Bur. Fish. Bull. 10: 389-436.

Rawitz, B. 1888. Der Mantelrande der Acephalen. Part I. Ostreacea. Jena. Z. Naturwiss., N. F., 15: 415-556.

Am. Zoologist, 1:273-289 (1961).

39

PHYSIOLOGY OF REPRODUCTION IN MOLLUSCS

Paul S. Galtsoff
Biological Laboratory, Bureau of Commercial Fisheries,
Woods Hole, Massachusetts

The present review deals with three major aspects of reproduction in molluscs: the anatomy of gonads and secondary sex organs; the reactions involved in the discharge and fertilization of the sex cells; hermaphroditism and sex change.

ANATOMY

In the primitive type of reproductive system found in *Amphineura,* in many bivalves, and in certain archaic Prosobranch gastropods, the germ cells are shed directly into the surrounding water and the fertilization of eggs takes place outside the maternal organism. A more elaborate system for the transmission of spermatozoa by means of copulatory organs has developed to various degrees of complexity in gastropods. Essentially this system is formed by the extension and differentiation of the male genital opening accompanied by the development of various accessory glands on the walls of the genital glands. In the cephalopods, sperm, enclosed in highly specialized spermatophores, are transmitted to the female by the modified arms. In some species the latter organs detach themselves from the animal and attain a certain degree of independence which permits them to swim over a considerable distance.

In spite of great variation one primitive characteristic is common to all the molluscs, namely, that the inner cavity of the gonads corresponds to the coelom and the sex products are discharged into the pallial cavity through the gonoducts which in many species retain connection with the nephridia.

The evolution of the reproductive organs from a most simple gonad found in bivalves, devoid of any accessory organs, to the most complicated system of pulmonates and cephalopods follows different patterns which serve to increase the chances for fertilization of eggs, to make possible correct timing of spawning and selective mating by various tropismatic reactions, and to promote survival of the progeny by various means of protection of developing eggs. By these methods a high level of population density may be maintained.

The gonad of the bivalves is a paired structure which in some species is fused in the middle. Its body consists of an acinous gland with many ramified blind tubules which open into ciliated canals. The latter join into a gonoduct through which the sex cells are discharged into the pallial cavity (Fig. 1). These ducts are usually short and ciliated, and they have no glands. In *Nucula* and some other genera, the sex gland opens into the nephridia and the sex cells are discharged through a common genito-renal duct.

The gonad may be located at the base of the visceral mass or in front of it, as for instance in *Neotrigonia.* More often, however, the sex glands extend into the mantle (*Mytilus, Yoldia*) and into the surface of the visceral mass, in which they form a ring-like layer, as for instance in oysters, clams, and pearl oysters (*Pinctada* sp.). In some bivalves marked pigmentation distinguishes the ovaries from the testes (sea scallop) while in others there are no such differences between the sexes. In hermaphroditic *Pandora,* ovaries occupy a dorsal position and are clearly separated from the more ventrally located spermaries. Such a topographical difference is not found, however, in the hermaphroditic species of oysters (*O. edulis, lurida*) in which eggs and sperm may develop in any part of the gonad.

The bulk of the gonad greatly varies with the season. The fully developed gonad of *C. virginica* forms a layer several millimeters in thickness, and in exceptional cases it may exceed 10-12 mm. The highest gonad development is reached shortly before spawning. At such a stage the ovary or the testis of *C. virginica* may form over 40% of the total body volume and weight, exclusive of shell. After spawning and absorption of the remaining ovocytes by phagocytes, the gonad is reduced to a few narrow islets of germinal epithelium. At this indifferent stage the sex of the mollusc is not recognizable.

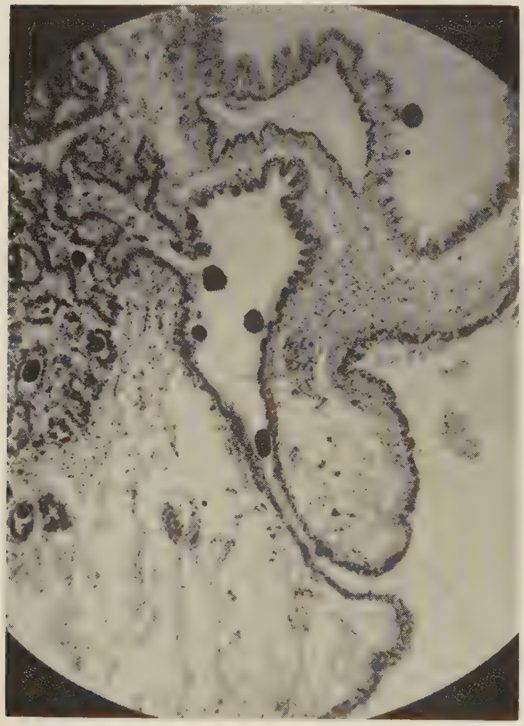


FIG. 1. Transverse section of an ovary of sexually mature *Crassostrea virginica* preserved during ovulation. Eggs are passing through a short gonoduct. Kidney reservoir on the top. × 50.

DISCHARGE OF GAMETES AND FERTILIZATION

Accessory sex organs are absent in the bivalves. The dispersal of eggs by the oviparous species, or of larvae by larviparous forms, is accomplished by the coordinated action of the adductor muscle, the epithelium of the gills, and the edge of the mantle.

In the majority of bivalve species the eggs are fertilized outside of the maternal organism and are left to their own fate. In fresh water *Unionidae* and some marine species, the eggs are incubated inside the female. In the simplest form this parental care of the progeny is accomplished by retaining the eggs inside the gills between the gill lamellae (*Ostrea edulis, O. lurida*). In fresh water *Unionidae* (Fig. 2) the gill tissue is modified to form brood chambers of various degrees of complexity. In *Sphaerium* the cells of the chambers supply glycogen, which is utilized by the embryos (Couteaux-Bargeton, 1948).

The oviparous molluscs as a rule produce an enormous number of eggs, the majority

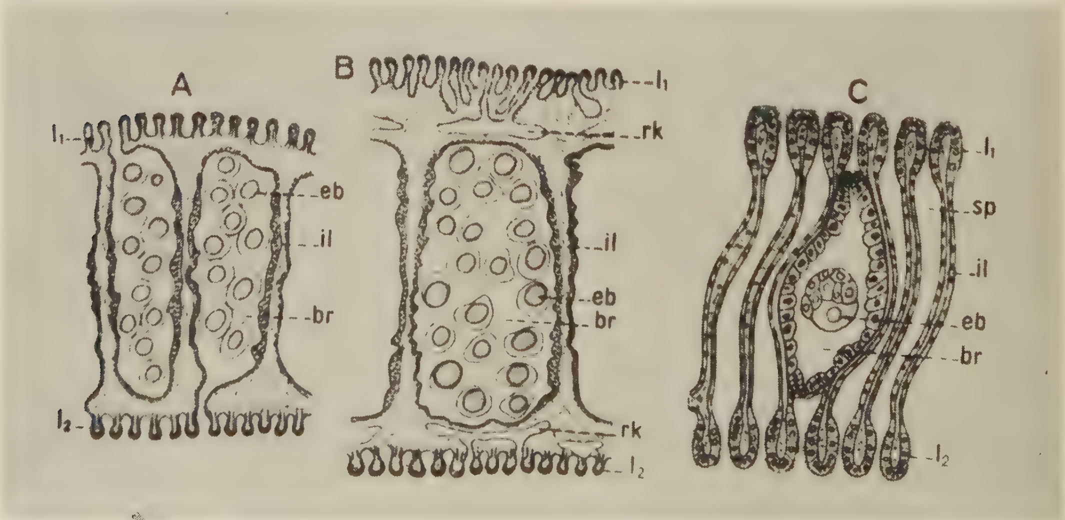


FIG. 2. Brood chambers of fresh water Unionidae in transverse sections. A—*Cyclas;* B—*Anodonta;* C—*Quadrula.* (From J. Meisenheimer, 1921; and Lefevre and Curtis, 1912).

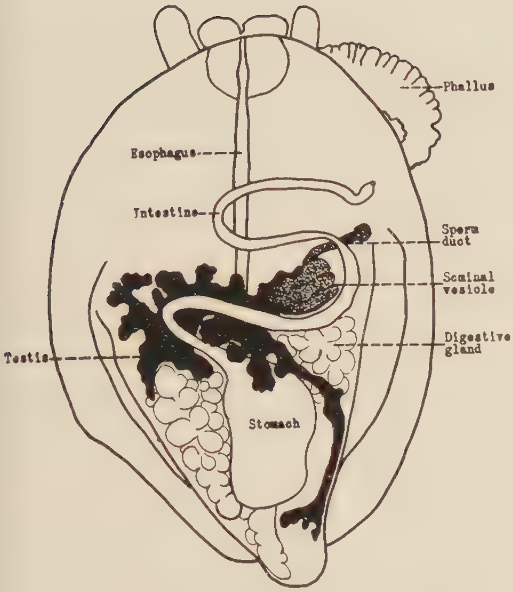


FIG. 3. Sex organs of small adult male *Crepidula plana*. (From Fig. 13, H. N. Gould, 1952, J. Exp. Zool., 119:131, with permission.)

of which perish before completing larval development. In other molluscs the apparent tendency for the economy of gametes is accomplished in various ways: by the elimination or shortening of the pelagic life of the larvae, as for example in *Macoma* and *Nucula* which lay only a few eggs; or by the failure to shed the sex products unless close to one of the other sex, as in the gastropod *Patella*, in some chitons, and in *Haliotis*.

Further evolution in the structure of organs of reproduction results in the appearance of special genital ducts and copulatory organs which convey, receive, and store the sperm for internal fertilization; in the development of the glands which secrete protective membranes for eggs; and in the development of special accessory organs used for sexual stimulation in mating.

A special organ of copulation, the phallus, of gastropods is usually a conspicuous organ noticeable without dissection. The development of the phallus is accompanied by the appearance of the seminal vesicle for the storage of sperm and the spermiduct, as can be seen, for instance, in the anatomy of *Crepidula plana* (Fig. 3). The sexual dimorphism is frequently, but not always, expressed in the difference in size—the males being considerably smaller than the females (Fig. 4).

The greatest complexity of reproductive system is attained in pulmonates. The organs of reproduction of these snails consist of the following main parts (Fig. 5): the hermaphroditic gland or ovo-testis (*o.t.*) and its duct (*h.d.*); the uterine enlargement of the duct (*u.*); the receptacle for storage of sperm which opens into the female gland (*r.s.*); albuminous gland (*alb.g.*) which secretes the egg membranes; finger-shaped accessory gland (*a.c.g.*); calciferous gland and sac full of calcite darts (*d.s.*) or arrows used in sexual stimulation. The male counterpart of the apparatus also begins with the ovo-testis from which the sperm is discharged through the spermiduct or vas deferens (*v.d.*); it has a phallus (*p*) with a long, hollow caecum or flagellum which secretes the spermatophores used for the transmittal of semen. In some gastropods the sper-

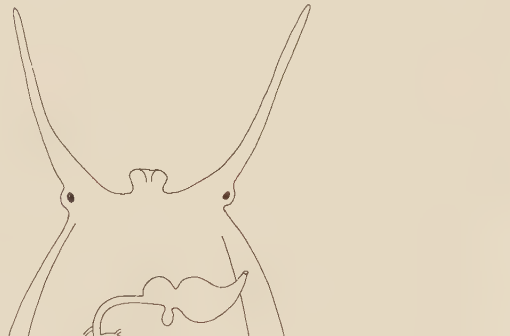


FIG. 4. Two successive stages in the development and absorption of phallus in *Crepidula nummaria*, from the mated male (right) to female phase (left). The phallus is absorbed and the uterus and ovary developed instead of seminal vesicle and spermary of the male. Adapted from W. R. Coe (1938).

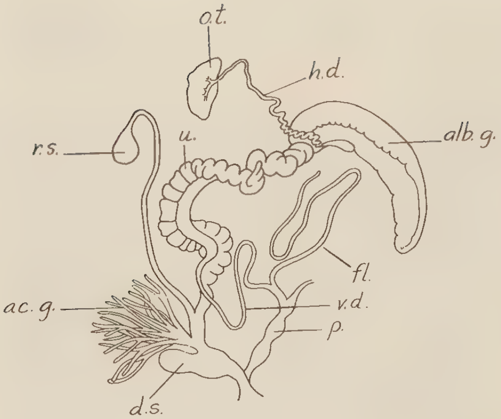


FIG. 5. Reproductive system of hermaphroditic land snail *Helix pomatia,* adapted from J. Meisenheimer (1921). ac.g.—finger-shaped accessory gland; alb.g.—albuminous gland; d.s.—calciferous gland and sac of calcite darts; fl.—flagellum; h.d.—duct from ovo-testis which leads to the enlarged oviduct and vagina (u.), and spermiduct; p—phallus; r.s.—seminal receptacle and its duct; v.d.—spermiduct.

matophores are furnished with denticulations, hooks, and similar structures (*Nania wallacei*) and are highly complex. It is apparent that an elaborate physiological control is necessary for a harmonious function of so many different parts.

Interesting dimorphism of male sex cells is found in many prosobranch gastropods. Their gonads normally contain two types of sperm: the ordinary spermatozoa with an oval or round head and long, slender tail; and the much larger sperm without nucleus, with undulating membranes instead of a flagellum, and large hexagonal bodies (Fig. 6). This type was described as vermiform, apyrene, oligopyrene, and giant sperm (Meves, 1903; Kushakewitch, 1913). They are less numerous than the ordinary sperm and are not capable of fertilizing eggs.

The apyrene sperm of *Viviparus* are over 100 μ long. They swim like spirochaetes and serve as carriers for the transport of a large number of normal spermatozoa which attach to them by their heads. In *Clathrus, Janthina,* and probably in *Cerithiopsis,* the apyrene spermatozoa are used for active delivery of normal sperm into the oviduct. In *Strombus bituberculatus* after copulation they are found only in the uterus but never in the seminal receptacles which are crowded by normal sperm. Reincke (1914) thinks that they serve as nursing cells for the eupyrene sperm and during this process exhaust the albuminal material which fills their large hexagonal bodies. It is also probable that apyrene sperm liberate some

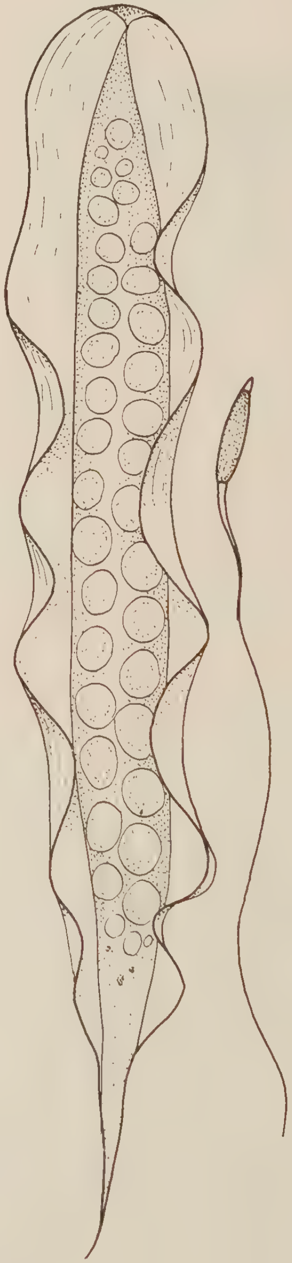


FIG. 6. Apyrene (left) and eupyrene (right) spermatozoa from the uterus of *Strombus bituberculatous.* From E. E. Reinke (1914).

substance which facilitates the insemination of eggs.

The dimorphism of male sex cells in Prosobranchia may be considered as a special adaptation for successful breeding of molluscs by delivering fertile spermatozoa to the uterus and maintaining them during storage.

The evolution of the reproductive apparatus of cephalopods follows a somewhat different direction. The male organs are of particular interest. The testis develops as a specialized portion of the coelomic wall. The spermatozoa pass through the so-called genital capsule into the spermiduct which opens externally into the pallial cavity either on the right side as in *Nautilus* or on the left side in *Dibranchia*. One or several glandular pouches on the spermiduct of *Dibranchia* show further specialization. They develop into the vesicula seminales and the prostate and form the terminal reservoir or Needham's sac for the storage of spermatophores. The sperm entering the initial part of the spermiduct is free; in the first glandular pouch it becomes surrounded by an envelope which is an invaginated tube, the deeper part of which constitutes a storage reservoir, and the more external part of which is greatly contracted and coiled into a spiral. In many species the spermatophores are small (Racovitza, 1894a, 1894b) but in *Eledone* they attain the length of 8 cm and in some Octopoda they are much longer. The longest ones appear to belong to the Pacific species, *Octopus honkongensis*; some of them when uncoiled were found to be almost four feet long (Lane, 1960).

The organ of copulation reaches a high degree of development in *Nautilus*. It is made of four modified tentacles, usually on the left side of the body. The arms are united to form a projection surrounded by a glandular area. This structure is called the spadix. In *Loligo, Sepia, Rossia,* and others, one arm is modified into a copulatory organ, the hectocotylus, which in some Octopoda (Fig. 7) becomes autonomous; when detached it is able to live and move until it penetrates into the pallial cavity of a female, attaches itself near the genital aperture, and releases the spermatophores.

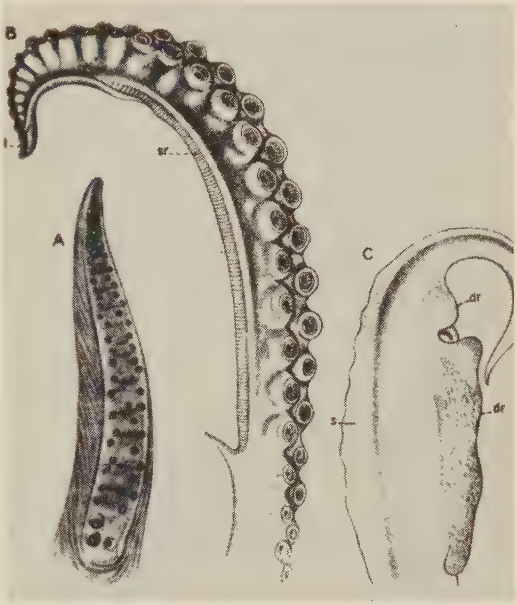


FIG. 7. Hectocotylus arms of three species of cephalopods. A—*Sepia orbignana;* B—*Octopus defilippi;* C—*Pterygoteuthis giardi* according to Jatta, 1896 (A and B) and Chun, 1910 (C). dr.—glandular cushion; l.—spoonlike tip; s.—swimming border; s.r.—spermatophore groove. From J. Meisenheimer, 1921.

The length of the hectocotylized arm greatly varies in different species. It reaches the very large size of about 16 inches in the octopus *Ocythoe tuberculata,* while the body of the male rarely exceeds 10 inches. Before detachment the arm remains coiled in a sheath or sac (Fig. 8).

The discovery of the male paper nautilus, *Argonauta argo,* is a famous page in the history of zoology. In 1827 Stephano delle Chiaje (quoted from Lane, 1960) found a small organism attached to the female argonaut and mistook it for a parasitic worm. Two years later Cuvier described it as a parasite and named it *Hectocotylus octopodis,* the generic name meaning "the arm of a hundred suckers." The error persisted until 1853, when Heinrich Müller published the first correct description of the male. The term hectocotylus survived and denotes now the modified arm of a male cephalopod.

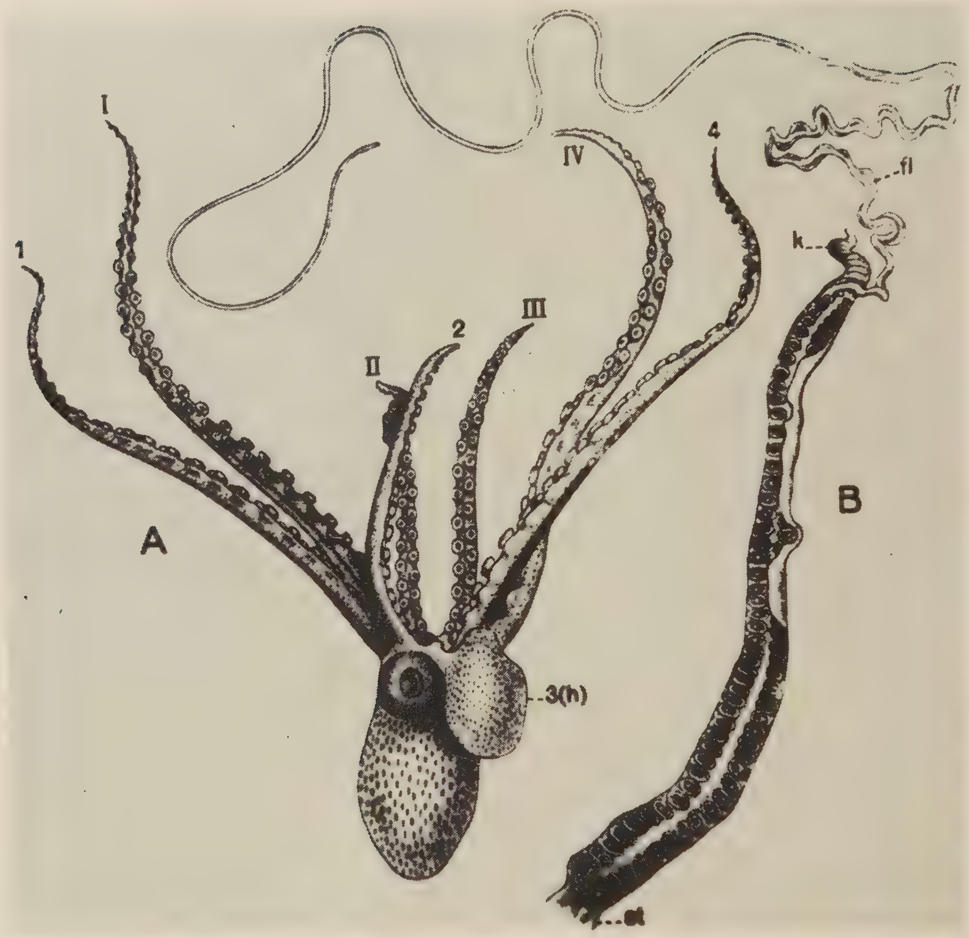


FIG. 8. Side view of the male *Ocythoe tuberculata* (A); (B)—detached and uncoiled hectocotylus arm. fl.—flagellum; k.—capsule of the arm's tip; st.—stalk of the hectocotylus; I-IV—the four arms of the left side of the body; 1-4—the arms of the right side. According to G. Jatta, 1896. From J. Meisenheimer, 1921.

The view found in zoological literature that the male argonaut is a parasite on a female body is not substantiated by observations. Males of this species were collected in plankton hauls and apparently are capable of living independently of females.

SEXUAL ACTIVITIES

The sexual rhythm is a cyclic phenomenon which starts with the development and maturation of sex cells and ends with their discharge. It may be of short duration repeating itself every month, as for instance in the tropical marine bivalves, or it may be seasonal and coincide with the rise of temperature to the optimum level typical for a given species (Orton, 1920; Coe, 1933, 1936a, 1936b; Korringa, 1957; Giese, 1959). A good example of such seasonal periodicity may be found in the American oyster, *Crassostrea virginica*, from the North Atlantic states. The proliferation of sex cells starts in this oyster with the onset of warm weather early in April and reaches the climax in the warmest months of the season, July and August. In the males the act of spawning begins with the liberation of sex cells from the follicles. Strong ciliary action propels the sperm through the genital ducts into the epibranchial chamber and on to the outside. No other organs are involved

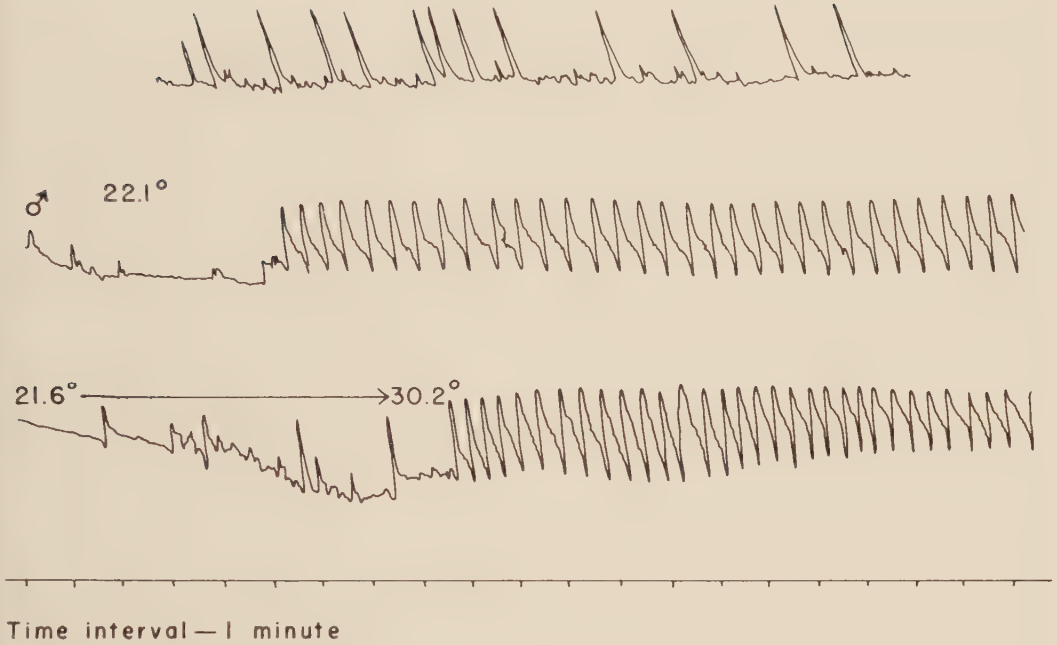


FIG. 9. Kymograph tracings of shell movements of *Crassostrea virginica* from Buzzards Bay, Massachusetts. Upper line—male oyster; middle line—sexually mature female stimulated to spawn by the sperm (♂); lower line—another sexually mature female stimulated to spawn by rapid rise of temperature from 21.6° to 30.2° C. The emission of sex cells was very copious in all three oysters.

in this simplest form of male spawning act. The release of mature spermatozoa can be triggered by a sudden rise in temperature or by various chemical substances, some of which may be normally present in the water while the others never occur in natural environment. The spawning of the male is provoked by the eggs or egg water of the same species, by the eggs and blood of other bivalves, and by thyroidin, various sugars, egg albumen, and extracts of sea weeds (Galtsoff, 1930, 1940). A ripe male oyster responds to these substances within a few seconds after their application to the mantle edge and gills. At the height of the spawning season the shedding of the sperm, once started, may continue for hours until the male is almost completely spent. Frequently, however, the shedding of sperm induced by chemical stimulus lasts a short time, from a few seconds to several minutes, but may be immediately repeated by the additional dose of stimulant. The sperm is dispersed in the surrounding water by the cloacal current without the assistance of shell movements. Occasional contractions of the adductor muscle shown in Fig. 9, first line, were recorded during copious spawning of the male. Sharp snapping of the valves are ejection reactions typical for normal feeding behavior of the oyster in water containing a large quantity of suspended particles. These contractions are not associated with the emission of sperm.

The response of a sexually mature oyster to chemical stimuli is non-specific.. The spawning reaction may be triggered by a great variety of organic substances. It is, therefore, understandable that under natural conditions the spawning of a population of oysters is initiated by the males. This conclusion is confirmed by numerous laboratory experiments and field observations.

The spawning reaction of the female oyster is more complex and involves several organs. The ripe ovary consists of a large number of follicles containing pear-shaped eggs attached to the walls. In spawning the eggs become detached and by strong ciliary action inside the ducts are transported to

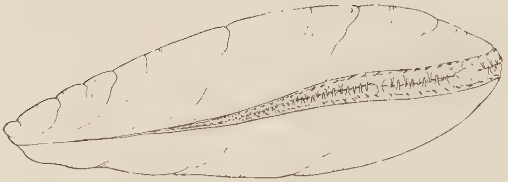


FIG. 10. Side view of the female oyster, *Crassostrea virginica* ready to discharge eggs. The pallium and the edges of the mantle seal the pallial chamber with the exception of a small oval-shaped window through which the eggs are dispersed in the water. Drawn from life. The distance between the two valves is slightly exaggerated.

the genital opening in the epibranchial chamber (Fig. 1). Instead of being carried out by the outgoing current which sweeps the chamber, the eggs are forced into the water tubes of the gill lamellae, penetrate the gill surface through the ostia, and fill the pallial cavity. To observe this process in the laboratory it is necessary to remove a part of the valve and stimulate the oyster to spawn. The ciliary motion of the gills is not reversed during spawning; the eggs are forced into the water tubes by the suction caused by the rhythmical contractions of the adductor muscle (Fig. 9, lines 2 and 3). The pallial curtain at this moment is temporarily sealed by the opposite edges of the mantle (Fig. 10) with the exception of a small oval-shaped opening, through which the eggs are dispersed (Galtsoff, 1938). Shell movements during spawning are characterized by the regularity and rapid rhythm of the contractions of the adductor muscle. We have not been able to induce this behavior of the muscle with any of the drugs so far tried.

The passage of eggs through the gills coincides with the moment when the adductor reaches the half-way point in its relaxation phase and the stretching of the muscle is temporarily slowed. This point is clearly marked as a short plateau or ledge on the relaxation curve (See Fig. 9, lines 2 and 3). Upon the completion of the relaxation phase, a sharp snapping of the valves closes the shells and propels the eggs to the outside. A delicate coordination of the functions of the gills, mantle, and adductor is necessary to accomplish this reaction. It is interesting that the nature of the initial stimulus of spawning has no effect on the type of muscular contractions. This can be seen in Fig. 9. The two lower lines are in every respect identical, although in one case spawning was induced by sperm, in another case by rapid warming of water. The spawning behavior which I have observed in *Crassostrea gigas, C. angulata,* and *C. commercialis* is identical to that described for *C. virginica.*

By cutting off the ligament, the shell movements can be stopped. Under this condition the eggs are not forced by suction into the water tubes of the gills but are washed away through the cloaca. They settle on the bottom in a dense mass in which only a few at the top of the heap have a chance to be fertilized. The complex mechanism for dispersal of eggs developed in the oviparous oysters obviously has value for the survival of the eggs and provides a better chance for fertilization.

Spawning of a sexually mature *C. virginica* may be initiated by a sudden rise of temperature, by sperm of the same or related species, or by the combined action of both stimuli. Sperm of other genera of bivalves are ineffective, and no response can be obtained with various substances which are effective in provoking the shedding of sperm. It is therefore obvious that the sexual response of the female is highly specific.

The latent period of female reaction varies from 6 to 20 minutes (Fig. 9, two lower lines) whereas the male responds to stimulation within a few seconds. Apparently different receptors are involved in the two cases. The long latent period of the female reaction suggests the possibility that the sperm may be absorbed, probably in the intestinal tract or by the gills. It takes about 6 to 8 minutes for a small particle to be delivered by the gills to intestine. The coincidence may be significant, but direct proof is lacking. It is, however, interesting that in the males, which also can be stimulated to spawn by the sperm, the response occurs within a few minutes instead of a few seconds as in the case of stimulation by egg water and various organic substances.

The active substance which stimulates spawning is extractable from mature spermatozoa by alcohol and benzene (Galtsoff, 1938b). The reaction initiated in the female by such extracts is not different from the effects of live sperm. Nelson and Allison (1940) reported that spermatozoa of the oyster carry another hormone-like substance which causes wide dilation of the ostia and in this way accelerates the transfer of water by the gills. They named the substance diantlin and thought that it was different from the substance which provokes spawning.

Other bivalves besides oysters can be induced by various physical and chemical methods to shed their gametes. Spawning of *Chlamys varia* is initiated by the gametes of the opposite sex and also by a number of mechanical and thermal stimuli such as rough handling, pinching of the mantle, and a sharp increase in temperature. Lubet (1951, 1955) found that thermic stimulation and the extracts of sex cells are more effective in inducing spawning in *Chlamys* than mechanical stimulation and that males are more responsive than females. Similar results were observed in *Mytilus galloprovincialis* and *M. edulis*; but the emission of sperm in these species could not be stimulated by eggs or egg extract, while the fresh sperm or sperm extract are effective in releasing the female spawning. There are indications that spawning of cold water species such as ocean scallop can be initiated by the increase of temperature, but the reaction of this mollusc to other stimuli has not been studied.

Iwata (1952, quoted from André, 1960) was able to provoke spawning in *Mytilus edulis* by electric current and by the injection of a 0.5 M solution of KCl.

Spawning stimuli applied to sexually mature *Crassostrea virginica* are sometimes effective on certain individuals but not on others taken simultaneously from the same population. The lack of response is not associated with insufficient maturity, since all individuals examined in the laboratory were found to have fully developed gonads. A similar condition has been noticed in *Crassostrea gigas* of the Pacific Coast of the United States. Apparently in these cases some unknown inhibition prevented the release of gametes. Lubet (1955) studied this phenomenon in *Chlamys* and *Mytilus* and found that the periods when spawning can be induced by external stimuli coincide with the periods of exhaustion of granules of the neurosecretory cells of the ganglia. The existence of neurosecretory cells in the nerve ganglia of Gastropoda and Scaphopoda was established by the work of Scharrer and Gabe, who also found them in many species of Lamellibranchs (Gabe, 1955). Excision of the cerebral ganglia in *Chlamys* and *Mytilus* provokes precocious spawning and the operated animals spawn much earlier than the controls. Excision of the visceral ganglia seems to retard spawning. Such retardation may be attributed to the isolation of the receptors of the mantle or to the prolongation of inhibitive action of cerebral ganglia. It seems significant that neurosecretion in ganglia cells precedes gametogenesis and that maximum accumulation of neurosecretory products occurs at the time of maturation of sex cells. The demonstrated absence of such secretion in the recently spawned-out animals may be interpreted as a condition which renders them receptive to the spawning-producing stimuli. The release of the inhibition in the molluscs with the excised cerebral ganglia confirms Lubet's hypothesis. His studies indicate that the spawning reaction of bivalves is definitely under the control of the nervous system.

Spawning of many bivalves under natural conditions is usually associated with a rise in temperature, although the exact level of temperature at which different species spawn varies greatly. This led to the assumption of the existence of a critical spawning temperature which acts as a trigger in releasing the germ cells. Observations by several biologists that the spawning of *C. virginica* at different latitudes frequently takes place at different temperatures, usually higher in the south and lower in the north, was explained by assuming the existence of distinct physiological species or races (Stauber, 1950; Loosanoff et al., 1951). Experimental evidence is not in harmony with this view. It has been shown in my laboratory that ripe adult female oysters taken simultaneously from the upper part of Buzzards Bay respond differently to thermic stimulation. Some of them spawned at a rise in temperature from 19-20° to 22-23°, while others, tested at the same time, required additional stimulation by sperm. Within the same population some individuals were able to spawn at 25-26° C, while others required 30° or even 31-32° C. Oysters unable to spawn at 25-26° C or at higher temperature were induced to spawn at those temperatures by the addition of sperm. It is unreasonable to assume that these individuals of common origin and living together belonged to different physiological species or races. The concept of "critical temperature" is inapplicable to the spawning of the American oyster. The responsiveness of the female to various degrees of stimulation depends on its "critical" state of ripeness rather than on specific temperature. In view of Lubet's findings, it appears reasonable to assume that this state is determined by the presence or absence of neurosecretory products. Only breeding experiments, which so far have not yet been made, can prove the existence of distinct "races" which require different temperatures to initiate ovulation.

Korringa (1957) observed that the three populations of *O. edulis* living at different latitudes release their larvae at three temperature levels (17.5°, 20°, and 25° C) and differ also "in the amount of warmth required for maturation of the sex products." Paradoxically, the population with the highest breeding temperature (25° C) is found at the northernmost fringe of distribution of the species near Bergen, Norway, and the "race" able to breed successfully at the 15° level lives at the southern limit of range near Vigo, in Spain. He explains this strange situation by the hydrographical conditions prevailing in these localities. No experimental evidence was presented by Korringa in support of this conclusion.

A suspension of fresh sperm or eggs always contains a certain amount of blood. It is therefore possible that blood of the spawning female may contain some stimulating substance. In the experiments conducted in my laboratory, the blood was collected from a female in which spawning was induced by raising the temperature. The 1 ml of blood withdrawn from the pericardium was immediately injected into the visceral mass of another ripe, but not spawning, female. The results were negative. Lubet (1955) repeated these experiments using *Chlamys varia* and *Pecten maximus*; he confirmed my finding that a spawning hormone is absent in the blood of the female.

With the greater complexity of the reproductive system of gastropods and cephalopods, their sexual activities become very elaborate. The mating in these molluscs involves several steps beginning with sexual recognition, followed by courting, copulation, deposition of eggs, and parental care of embryos and larvae.

Many marine gastropods have the tendency to climb over vertical surfaces above the bottom. The negative geotropism greatly increases during the breeding season, with the result that eggs of such snails as *Urosalpinx cinerea, Thais haemastoma, Tritonelia japonica,* and others are laid above the bottom on rocks, sticks, sea walls, and various submerged objects. This behavior is successfully utilized by shellfish growers for trapping the snails in wire bags filled with shells and rocks, or by using bamboo sticks placed on the oyster bottom. The latter method is widely employed in the delta of the Mississippi River to control the inroads of *Thais haemastoma,* which is highly destructive to oysters. The laying of eggs by one conch attracts the others and soon several egg-laying females are found on one stick while other sticks nearby contain none. Huge masses of egg cases are collected in this manner.

The highest complexity of sexual activities is reached in land snails and slugs. The

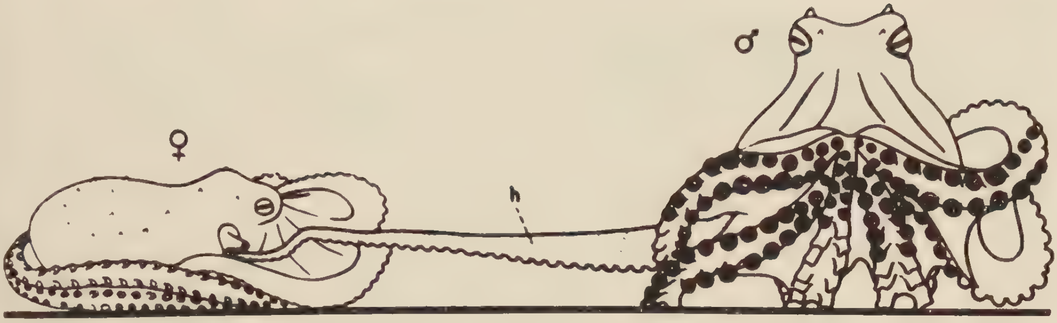


FIG. 11. The mating of *Octopus vulgaris.* The male has attached itself to the wall of the aquarium and extended his hectocotylus (h) into the mantle cavity of the female. From J. Meisenheimer, 1921.

crucial point in the mating of these animals is the transfer of sperm, enclosed in a spermatophore, to the genital opening of the partner. The spermatophore is covered with a chitinous envelope which is secreted inside the tubular outgrowth of the copulatory organ, the so-called flagellum. The pairing animals entwine together for several hours, being enclosed in a copiously secreted mucus. They perform a complicated act which the German zoologists of the past century called "Liebesspiel" or love game. The land snails, *Helix,* at the beginning of the act throw sharp, calcareous arrows, the love darts or "telum amori," and exchange them by lodging these weapons in the integument, sometimes inflicting serious wounds. This behavior precedes copulation and serves to enhance the sexual stimulation. Sometimes the wound is too severe and the partners move away. The actual transfer of spermatophores is assisted by the secretion of special mucous glands near the mouth of the vagina (Meisenheimer, 1907).

The behavior of the hectocotylyzed arm of cephalopods is of great interest, but unfortunately the physiology of this semi-independent organ is not known. One must assume that hectocotyli are equipped with an adequate nervous mechanism for proper orientation in reaching the female and for depositing the spermatophores in the precise position in front of the female's genital opening during copulation.

Courtship and mating of the octopus (Racovitza, 1894b) and *Sepia* (Tinbergen, 1939) starts with the location of the female by the male. As soon as the animals are near each other the male displays optical signals by means of color change, assumes a special posture, and moves its body in a peculiar manner. These actions are apparently recognized by the female (Fig. 11).

The nuptial coloration of *Sepia* is very conspicuous. It consists of zebra-like white and colored stripes on the body and a deep red coloration of part of the head. In assuming nuptial position the male extends sideways the fourth (ventral) arm, changes its color, and widely opens his eye on the side of the outstretched arm. The throwing of large quantities of water, biting and chewing the partner while holding each other in the arms are of common occurrence among the sexually excited animals. Because the color change is due to the contraction and expansion of chromatophores, one may suspect neuro-hormonal control of these reactions; but the problem has not been studied experimentally, probably because of the great difficulty involved in surgical operations on these animals, which are difficult to keep in captivity.

The mating of the common octopus of Europe may last for several hours or even a whole day. Maternal instinct is present. The interesting behavior of a female octopus of the Pacific Coast during mating and in protecting the newly laid cluster of eggs was described by Fisher (1923) and Fox (1938).

The copulation of squids is best known through the work of Drew (1911) on *Loligo*

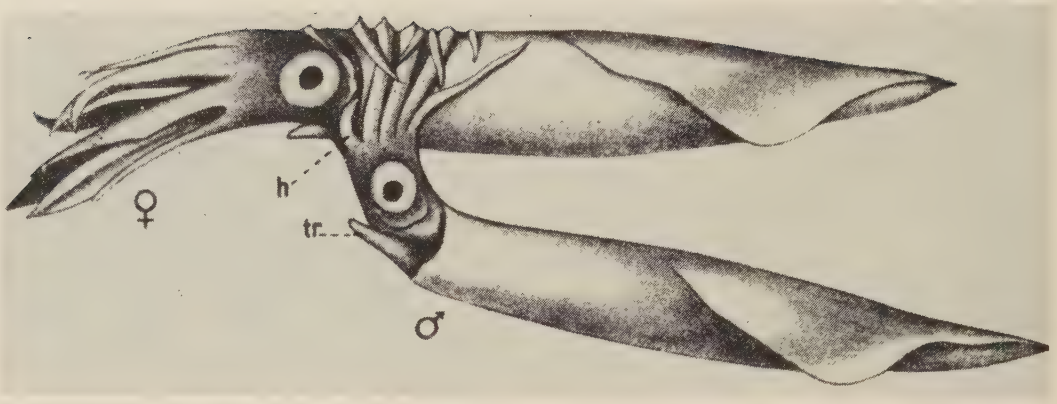


FIG. 12. Mating of squid, *Loligo pealii.* From G. Drew, 1911.

pealii. An elaborate courtship precedes mating. During the preliminary act the male squid swims alongside the female, spreading his arm and displaying a dark red color caused by the expansion of its chromatophores. He may come in contact with the female, grasping her around her head with his arms, with the lower sides of both animals in close contact (Fig. 12). At this moment the hectocotylus plucks out a bunch of spermatophores and inserts them into the mantle cavity where they become attached near the oviduct. In another position the two animals join their heads and the spermatophores are placed on the buccal membrane of the female. The squid's spermatophore is a very complex structure equipped with a special reservoir for sperm, ejaculatory apparatus, and a cement body.

The immobile sperm inside the spermatophores are activated by contact with sea water and released through the ruptured reservoir. At this time the eggs are laid and fertilized. Large numbers of spawning males and females, which at other times live separately, gather together and attach large egg masses to the common pile. The fertility of some cephalopods is enormous. Scripps Institute recorded several instances in which fishermen were not able to raise their nets heavily laden with the eggs of the Pacific squid *Loligo opalescens.* On another occasion an area of about 200 acres of sea bottom near LaJolla, California, was covered with the eggs of this species. The European squid, *Loligo vulgaris,* was reported to lay up to 42,000 eggs in one egg mass (Lane, 1960).

SEX CHANGE

With the exception of the cephalopods, in which the sexes as a rule are separate, the gonads of other classes are unstable and may alternate from male to female or vice versa. Hermaphroditism is encountered in many gastropods and in a few bivalves. The alternations of sexuality in the larviparous oysters and in *Teredo* are probably the best known examples of the sex changes which take place in molluscs.

In the so-called hermaphroditic molluscs (*Ostrea edulis, O. lurida,* and *Teredo*) each normal individual shows a tendency toward rhythmic alternation of functional sexual phases. Several of these phases may be completed in a lifetime, starting with a protandric bisexuality which is generally characteristic for the earliest sexual stage.

Spärck (1925) showed that *O. edulis* in Limfjord, Norway, is a protandric alternating hermaphrodite, in which the sperm-producing period is followed by the period during which eggs are formed, and then again the gonad shifts to the production of sperm. The genital cells not used in the current summer may be utilized in the next breeding period. The interval between the two consecutive female phases is shorter the warmer the water. The sequence of male-female phases is variable (Orton, 1927, 1933) and other combinations such as: male—female—female; male—male—female; and a rare change of female–male–female take place in *Ostrea edulis* and in *Teredo.*

Histological studies show that the gonad of the American oyster is essentially bisexual. In young *Crassostrea virginica* the cortical layer of gonad follicles consists of ovogonia surrounding the spermatogenic cells. The inherent tendency of oysters toward an alternation of sexuality is probably influenced by environmental conditions aborting one or the other phase. More favorable environment stimulates the growth of ovogonia (Coe, 1936a, 1936b) but neither season, temperature, nor ecological conditions can alter the inherent sequence of sex change. Outside influences may, however, prolong or shorten the durations of sexual phases and affect the number and proportion of the gametes in young oysters (Coe, 1932).

The adult *C. virginica* functions each breeding season either as a male or as a female. Sex change in this species takes place between the two breeding seasons and occurs in a relatively small percentage of the population. In this way *C. virginica* differs from the larviparous *O. edulis* or *O. lurida,* in which the male and female phases follow each other with more or less regular rhythm (Coe, 1934).

The young of *C. virginica* are predominantly male. The percentage of females at the first breeding season is highly variable (from 3 to 33%) in different localities and at different years (Coe, 1936a). An approximate 1:1 sex ratio is usually established in the two-year-old class. In older specimens the sex change is less regular. Needler (1932) and Amemiya (1929) demonstrated this for the adults of *C. virginica* and *C. gigas* respectively, by determining the percentages of sexes in two samples taken during two consecutive years, and by histological examination of excised pieces of gonad and the marking of the individuals which were examined. Injury to the tissues, which might affect the gonad, can be avoided by determining the sex of ripe oysters by inducing each of them to spawn individually and by repeating the procedure in the following years. Using this technique I observed the spawning of 202 adult oysters from Long Island Sound and determined the sex changes that took place in each of these animals during consecutive years. The oysters were four years old at the start of the experiment. Each of them was stimulated to spawn by raising the temperature of the water; the spawning reaction was recorded on kymographs; the sex was determined by microscopic examination of the discharged sex cells; and an identifying number was engraved in the right valve. After the laboratory test was completed, the oysters were returned to the outdoor tanks or placed in cages in the harbor where they were kept until the next spawning season. The procedure was repeated for five consecutive years. The results presented in Table 1 show the changes in the sex ratios which occurred during this period.

TABLE 1. *Changes in the percentage of male and female* Crassostrea virginica *tested consecutively each year*

Age in years	Males	Females	Not spawning	Total number
4	64.4	35.6	0	202
5	65.2	32.6	2.2	181
6	61.2	31.6	7.2	139
7	50.1	40.3	9.6	104
8	44.1	41.2	14.7	68

The prevalence of males at the start does not represent the normal sex ratio among four-year-old oysters. The males as a rule are more responsive to stimulation and more readily react to the increase in temperature than the females. Stimulation by adding sperm was avoided in order not to miss the possibility of finding a hermaphrodite. It is apparent that the percentage of females suddenly increased in the seven-year-old oysters. The tendency toward retaining the female phase is more clearly seen by examining the sex-reversed oysters which survived for four years and during this time alternated their sex once or several times. The sequence and frequency of changes in these oysters from male to female or vice versa does not follow a distinct pattern (Table 2).

At the start the group of 31 four-year-old oysters consisted of 23 males and 8 females.

TABLE 2. *Sequence and frequency of sex reversal in the group of oysters which changed sex and survived for four years*

Sequence	Frequency	Sequence	Frequency
♂ ♂ ♀ ♀ ♀	4	♀ ♂ ♀ ♀ ♀	2
♂ ♂ ♂ ♀ ♂	4	♀ ♀ ♀ ♀ ♂	1
♂ ♂ ♂ ♀ ♀	3	♀ ♂ ♂ ♂ ♀	1
♂ ♂ ♂ ♂ ♀	3	♀ ♂ ? ♀ ♀	1
♂ ♀ ♂ ♂ ♀	1	♀ ♀ ♀ ♂ ♂	1
♂ ♀ ♂ ♀ ♀	1	♀ ♀ ♂ ♂ ♂	1
♂ ♀ ♀ ♀ ♀	1	♀ ♂ ♂ ♂ ♂	1
♂ ♂ ? ♀ ♀	1		
♂ ♂ ♀ ? ♀	1		
♂ ♀ ♂ ♂ ♂	1		
♂ ♂ ♀ ? ♀	1		
♂ ♂ ♀ ♂ ♂	1		
♂ ♀ ♂ ♀ ♂	1		

	Number of Males	Number of Females
Start	23	8
End	11	20

Question mark indicates failure to spawn.

By the end of the fourth year (the fifth year in which sex was determined) there were 11 males and 20 females. No distinct pattern is apparent in the rhythm of changes except the greater persistence of the female phase. One oyster of the group changed its sex every year: M–F–M–F–M. The inherent tendency toward an alternation of sexuality in the oviparous species is well pronounced among the year-old class (Coe, 1936a) but in a few oysters it persists throughout their life.

The change from male to female is accompanied by changes in the spawning behavior which is manifested in the type of muscular contraction curve and in the discharge of eggs through the gills (Fig. 13). Frequently, however, a fully developed female reaction appears in sex-reversed oysters only toward the middle of the breeding season while the first spawning reaction of the season may still be of the male type, i.e., the eggs are discharged through the cloaca in a male-like fashion (Fig. 14). Toward the end of the breeding season full female characteristics are reestablished and the eggs are dispersed through the cloaca. The change from female to male is always complete with the alteration of sex in the gonad.

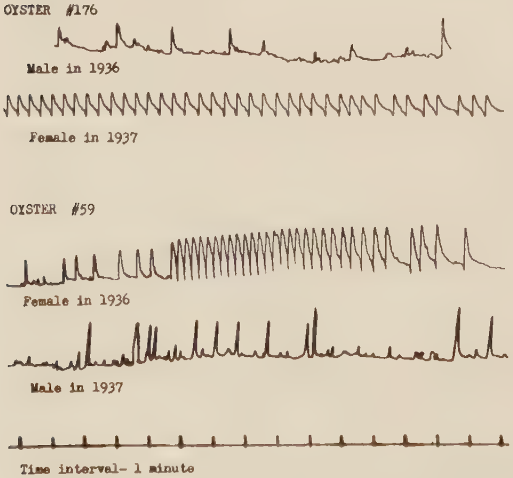


FIG. 13. Spawning reactions of sex-reversed oysters. Complete change in behavior from male to female phase (upper part) and from female to male phase (lower part).

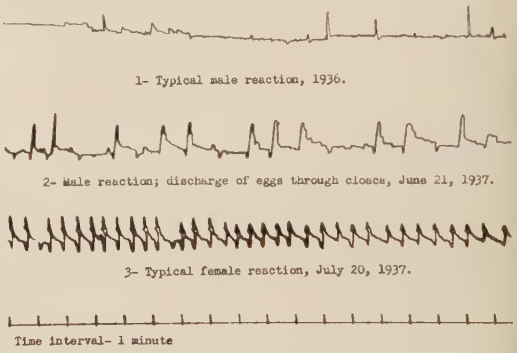


FIG. 14. Spawning reactions of the male oyster which in the following year changed into female but retained male behavior (2nd line). Full female reaction developed later (3rd line).

The spawning record of a hermaphroditic oyster (Fig. 15) combined the characteristics of both sexes. Eggs and sperm were discharged through the cloaca, and the rhythmical contractions of the adductor muscle were not fully developed.

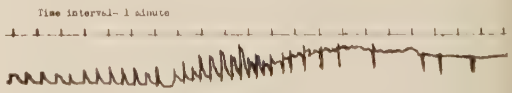


FIG. 15. Spawning of an hermaphroditic oyster.

The development of rhythmic contraction of the adductor muscle of a spawning female and the peculiar position assumed by the pallium are probably due to nervous impulses associated with the release of eggs from the ovary. The spawning syndrome fades toward the end of the breeding season when the major portion of the eggs have

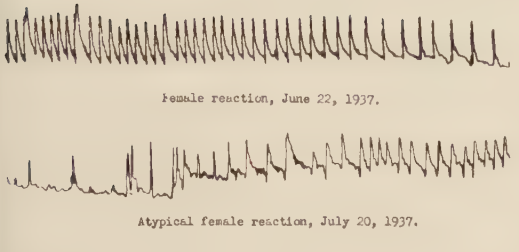


FIG. 16. Change from typical to atypical spawning reaction of a female *Crassostrea virginica* by the end of the breeding season. During the second reaction (lower line) eggs were discharged through the cloaca.

been already discharged. Consequently, nontypical spawning reactions can be observed at the very end of the breeding period. The record reproduced in Fig. 16 illustrates the point. The last and very light spawning of the oyster is atypical; (2nd line), the eggs were discharged through the cloaca and the pallium remained wide open.

The sex change of the gastropod *Crepidula* (Gould, 1952; Coe, 1936c) is of particular interest because of the apparent effect of association of the mollusc with individuals of the opposite sex. *Crepidula fornicata* forms a group of individuals attached in the form of a chain with the youngest and smallest male on the top. The oldest specimens at the bottom of the chain are mature females, while the hermaphrodites are in an intermediate position. Isolation of the male promptly terminates the male phase. The changes from male to female in this and other species can be accelerated or inhibited, but the sequence can not be altered. Coe (1936c) found no evidence of action of a masculinizing hormone which may have emanated from the female. He offered the suggestion (not supported, however, by experimental evidence) that stimuli received by the male through sense organs are of such nature as to influence masculine characteristics, presumably by the mediation of hormones secreted within the body. Sex changes in *Crepidula* offer an excellent opportunity for experimental study of the physiology of sex change, but the problem has not yet been adequately explored.

In several gastropods the change of sex from male to female phase may be correlated with the increase in body length. This has been shown for *Patella coerulea* (Orton, 1927; Bacci, 1947) and for *Fissurella nubecula* and *Calyptraea chinensis,* a species closely related to *Crepidula.* The problem was recently reviewed by Montalenti (1958) and, therefore, will be only briefly mentioned here. In *Patella coerulea* the predominant number of individuals at the beginning of life are functional males. Some of them later change sex and become females, but the transitional phase when both sperm and eggs are formed in the gonad is very short. The correlation between the percentage of individuals in the male phase and body length is clearly shown in the curves published by Bacci (1949). In the case of *Calyptraea chinensis* (Bacci, 1951), the sex change is very abrupt at the size of 6-9 mm when the percentage of males drops to zero. Bacci believes, however, that approximately 8% of individuals of *Patella coerulea* consist of primary females or males. This group comprises small females which did not undergo a previous male phase and large males which apparently are not going to become females. The larger percentage (15%) of individuals that undergo sex change is found in the size class of 20-22 mm. The frequency curve of changes declines symmetrically from this peak to the 7% level in the 14-16 mm class and to about 5% in the 26-28 mm class.

The presence of pure males and females in the population seems to support the hypothesis that sex variability in *Patella* and other gastropods is genetically determined. On the basis of such observations Montalenti and Bacci (Montalenti, 1958) advanced a theory that the time at which sex reversal occurs is mainly determined by a genetic condition upon which environmental factors may exert their role. The effect of environment on sex changes in molluscs is mentioned as a controlling factor by Coe and others, but so far no experiments have been undertaken to determine those factors of environment which influence the frequencies and the direction of sex change.

The physiology of reproduction in molluscs, as may be seen from this review, remains an incomplete and promising chapter of biology.

REFERENCES

Amemiya, Ikusaku. 1929. On the sex change of the Japanese common oyster, *Ostrea gigas* Thunberg. Proc. Imp. Acad. 5:284-286.

André, Franc. 1960. Classe des Bivalves, Tome V, fasc. II:1844-2133. *In* Traité de biologie, Pierre P. Grassé, Directeur.

Bacci, Guido. 1947. L'inversione del sesso ed ie ciclo stagionale della gonade in *Patella coerulea* L. Pubbl. Sta. Zool. Napoli 21:183-217.

———. 1950. Osservazioni statistiche sulla determinazione dei sessi in *Patella coerula* L. Pubbl. Sta. Zool. Napoli 22:26-39.

———. 1952. L'ermafroditismo di *Calyptraea chinensis* L. e di altri Calyptraeidae. Pubbl. Sta. Zool. Napoli 23:66-90.

Chun, Carl. 1910-1914. Die Cephalopoden. I Teil Oegopsida. Wiss. Erg. Deutsch. Tiefsee. Exped., Valdivia. Jena. 401 p.

Coe, Wesley R. 1932. Sexual phases in the American oyster (*Ostrea virginica*). Biol. Bull. 63:419-441.

———. 1933. Sexual phases in *Teredo*. Biol. Bull. 65:283-303.

———. 1934. Alternation of sexuality in oysters. Am. Naturalist 68:1-15.

———. 1936a. Environment and sex in the oviparous oyster, *Ostrea virginica*. Biol. Bull. 71:353-359.

———. 1936b. Sequence of functional sexual phases in *Teredo*. Biol. Bull. 71:122-132.

———. 1936c. Sexual phases in *Crepidula*. J. Exp. Zool. 72:455-477.

———. 1938a. Influence of association on the sexual phase of gastropods having protandric consecutive sexuality. Biol. Bull. 75:274-285.

———. 1938b. Conditions influencing change of sex in mollusks of the genus *Crepidula*. J. Exp. Zool. 77:401.

———. 1940. Divergent pathways in sexual development. Science 91:175-182.

Couteaux-Bargeton, Marie. 1948. Mode de nutrition dans des embryons dans les poches incubatrices des Lamellibranches Sphaeridés. Compt. Rend. Acad. Sci. Paris 226:1746-1747.

Delle Chiaje, Stefano. 1822-1830. Memorie sulla storia e notomia degli animali senza vertebre del regno di Napoli. Naples. Frateui Fernandes. (Quoted from Lane, 1960.)

Drew, Gilman A. 1911. Sexual activities of the squid, *Loligo pealii*. J. Morphol. 22:327-360.

Fox, Denis L. 1938. An illustrated note on the mating and egg brooding habits of the two-spotted octopus. Trans. San Diego Soc. Nat. Hist. 9:31-34.

Fisher, W. K. 1923. Brooding habits of a cephalopod. Ann. Mag. Nat. Hist., 9th Series 12:147-149.

Gabe, M. 1955. Particularités histologiques des cellules neurosécretrices chez quelques Lamellibranches. Compt. Rend. Acad. Sci. Paris 240: 1810-1812.

Galtsoff, Paul S. 1930. The role of chemical stimulation in the spawning reactions of *Ostrea virginica* and *Ostrea gigas*. Proc. Natl. Acad. Sci. U.S.A. 16:555-559.

———. 1932. Spawning reactions of three species of oysters. J. Wash. Acad. Sci. 22:65-69.

———. 1938a. Physiology of reproduction of *Ostrea virginica*. I. Spawning reactions of the female and male. Biol. Bull. 74:461-486.

———. 1938b. Physiology of reproduction of *Ostrea virginica*. II. Stimulation of spawning in the female oyster. Biol. Bull. 75:286-307.

———. 1940. Physiology of reproduction of *Ostrea virginica*. III. Stimulation of spawning in the male oyster. Biol. Bull. 78:117-135.

Giese, Arthur C. 1959. Comparative physiology: annual reproductive cycles in marine invertebrates. Ann. Rev. Physiol. 21:547-576.

Gould, Harley N. 1952. Studies on sex in the hermaphrodite mollusk *Crepidula plana*. IV. Internal and external factors influencing growth and sex development. J. Exp. Zool. 119:93-164.

Jatta, Giuseppe. 1896. Cefalopodi viventi nel golfo di Napoli (Sistematica). Fauna und Flora Golfes von Neapel, 23rd Monograph. Berlin. 268 p.

Korringa, Peter. 1957. Water temperature and breeding throughout the geographical range of *Ostrea edulis* L. Année Biol. Ser. 3, 33:1-15.

Kushakewitch, S. 1913. Studien über den Dimorphismus der männlichen Geschlechtselemente bei den Prosobranchia I. Arch. Zellforschung 10: 237-323.

Lane, Frank W. 1960. Kingdom of the octopus. Sheridan House, New York. 300 p.

Lefevre, George, and Winterton C. Curtis. 1912. Studies on the reproduction and artificial propagation of fresh-water mussels. Bull. Bur. Fisheries 30:105-201.

Loosanoff, Victor L. 1945. Precocious gonad development in oysters induced in midwinter by high temperature. Science 102:124-125.

Loosanoff, Victor L., and C. A. Nomejko. 1951. Existence of physiologically different races of oysters, *Crassostrea virginica*. Biol. Bull. 101:151-156.

Lubet, Pierre. 1951. Sur l'émission des gamètes chez *Chlamys varia*. Compt. Rend. Acad. Sci. Paris 233:1680-1681.

———. 1955. Cycle neurosécretoire chez *Chlamys varia* L. et *Mytilus edulus* L. (Mollusques lamellibranches). Compt. Rend. Acad. Sci. Paris 241: 119-121.

———. 1956. Effets de l'ablation des centres nerveux sur l'émission des gamètes chez *Mytilus edulis* L. et *Chlamys varia* L. (Mollusques lamellibranches). Ann. Sci. Nat. Zool. Ser. 11, 18:175-183.

Meisenheimer, Johannes. 1907. Biologie, Morphologie und Physiologie des Begattungsvorgang und der Eiablage von *Helix pomatia*. Zool. Jahrb. 25: 461-502.

———. 1921. Geschlecht und Geschlechter im Tierreiche I. G. Fisher, Jena. 896 p.

Merrill, Arthur S., and John B. Burch. 1960. Hermaphroditism in the sea scallop, *Placlopecten magellanicus* (Gmelin). Biol. Bull. 119:197-201.

Meves, Friedrich. 1903. Ueber oligopyrene und apyrene Spermien und über ihre Entstehung, nach Beobachtungen an Paludina und Pygaera. Arch. Mikrosk. Anat. 61:1-84.

Montalenti, G. 1958. Perspective of research on sex problems in marine animals, p. 589-605. *In* A. A. Buzzati-Traverso, [ed.], Perspectives in marine biology. Univ. Calif. Press.

Needler, Alfreda B. 1932. Sex reversal in *Ostrea virginica*. Contrib. Canad. Biol. Fisheries 7:285-294.

Nelson, Thurlow C., and James B. Allison. 1940. On the nature and action of diantlin; a new hormone-like substance carried by the spermatozoa of the oyster. J. Exp. Zool. 85:299-338.

Orton, J. H. 1920. Sea temperature, breeding and distribution in marine animals. J. Mar. Biol. Assoc. of U. K. (N. S.) 12:339-366.

———. 1927. Observations and experiments on sex change in the European oyster (*O. edulis*). Part I. J. Mar. Biol. Assoc. of U. K. (N. S.) 14:967-1045.

———. 1933. Observations and experiments on sex change in the European oyster (*O. edulis*). Part III and Part IV. J. Mar. Biol. Assoc. of U. K. (N. S.) 19:1-54.

Racovitza, Emile G. 1894. Notes de biologie. Accouplement et fécondation chez l'*Octopus vulgaris* Lam. Arch. Zool. Exp. Gen. 3rd Serie 2: 21-54.

———. 1894. Notes de biologie. Moeurs et reproduction de la *Rossia macrosoma* (D. Ch.). Arch. Zool. Exp. Gen., 3me Ser. 2:491-539.

Reinke, Edwin E. 1914. The development of the apyrene spermatozoa of *Strombus bituberculatus*. Carnegie Inst. Wash. Publ. No. 183:195-239.

Robson, G. C. 1926. On the hectocotylus of the cephalopoda—a reconsideration. Proc. Malacol. Soc. London 17:117-122.

Spark, R. 1925. Studies on the biology of the oyster, (*Ostrea edulis*), in the Limfjord, with special reference to the influence of temperature on the sex change. Rept. Danish Biol. Sta. 30:1-84.

Stauber, Leslie A. 1950. The problem of physiological species with special reference to oysters and oyster drills. Ecology 31:109-118.

Tinbergen, L. 1939. Zur Fortpflanzungethologie von *Sepia officinalis* L. Arch. Neerl. Zool. 3:323-364.

40

Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Thirteenth Annual Session, November, 1960
Pages 131-134

The Future of the United States Oyster Industry From a Biologist's Viewpoint

John B. Glude
U.S. Bureau of Commercial Fisheries
Washington, D.C.

Oysters are one of our great natural resources and the oyster industry is one of the oldest in the United States. It is a variable industry, ranging from a wild fishery upon natural stocks of oysters to highly specialized farming carried out on private lands.

Many adversities face the oyster industry and cause speculation about the future of the resource and those individuals and companies engaged in it. The following discussion is an attempt to consider the biological aspects of the oyster industry; leaving to others the problems of processing, marketing, sociology, politics, and economics.

How can we predict the future of this sprawling industry which is spread over every coastal State, which uses many different methods, and has various local problems with little in common except the final product? Logically, we should examine the past to indicate trends. We should look closely at the present for today's problems are the best known, but with care lest we overemphasize their importance. Finally, we should look to the future in the light of our experience in the past, the present status and the hopes and problems which we can foresee.

The Past

Production trends on the Atlantic coast have been downward from peaks which were reached many years ago; yet in other places the reverse is true. For example, the Pacific oyster industry, which began less than 30 years ago, now has a stabilized production of over 10 million pounds of oyster meats per year. Production in the Gulf States has varied from year to year but this area continues to produce a substantial share of the nation's oysters.

The Present

These present problems of the oyster industry appear to be almost insurmountable:

1. *Decrease in Areas Suitable for Oyster Production.* Narragansett Bay, Rhode Island, for example, was once a major center of oyster culture in New England. At the present time it produces no oysters despite repeated attempts to gather seed and to grow seed transplanted from other locations. Although the exact causes are not known, it must be concluded that this area is no longer suitable for oyster production. Development of coastal and estuarine areas for industry, recreation or residential purposes has already destroyed many areas which were suitable for oyster production. This trend will certainly continue.

2. *Oyster Predators.* Hordes of starfish from the dominant 1957 year class have almost destroyed the oyster industry of Long Island Sound. Oyster drills in Long Island Sound and the saltier part of the Delaware Bay and coastal bays of Maryland and Virginia are a serious deterrent to economic oyster culture. Other species of oyster drills in the Gulf of Mexico and in the Northwest likewise cause serious losses of small oysters.
3. *Mass Mortalities of Oysters in Delaware Bay, Coastal Delaware, Maryland and Virginia and Chesapeake Bay.* Major losses have occurred since 1957. Although cooperative research is under way, the exact cause of these mortalities has not been determined.
4. *Oyster Mortalities Caused by the Fungus Dermocystidium.* In the Gulf of Mexico and in the warmer waters of the Atlantic coast this parasite kills a large percentage of the oysters each year.
5. *Shortage of Seed Oysters.* North of Virginia the industry is limited by a shortage of seed oysters since reproduction is less dependable than it is in the South Atlantic and Gulf States.
6. *Control of Mud Shrimps in the Northwest.* Recent increases in abundance of mud shrimps *Callionassa* and *Upogebia* have caused the destruction of many acres of valuable oyster land in Washington. These pests burrow through the bottom, making it too soft for oyster culture and increasing the deposition of the silt over the oysters.
7. *Unexplained Oyster Mortalities in Washington and British Columbia.* Approximately ten instances of oyster mortalities are reported to the Washington State Department of Fisheries each summer. Similar oyster mortalities also are reported from British Columbia. Causative agents or factors are unknown.
8. *Economic Problems.* While the cost of producing Pacific oysters has increased, the selling price is the same or lower than it was ten years ago. In other areas prices are favorable but supplies of oysters are limited.
9. *Importation of Foreign Oysters.* Canned and smoked oysters from Japan are being imported in increasing quantities. A new plant at Hiroshima, Japan, is producing frozen oysters especially packaged for shipment to the United States.

For each of the problems listed above, solutions can be found. The decrease in areas suitable for oyster production is part of the general "estuarine problem." The Gulf State Marine Fisheries Commission and the Atlantic States Marine Fisheries Commission have recognized the importance of this problem. States and Federal agencies are expanding research to find ways of preserving essential coastal bays and estuaries and replacing those which are lost.

The control of predators appears much more promising than it did several years ago. Recent research has disclosed chemical and physical methods which after thorough testing should be available for commercial use.

Cooperative research by State and Federal scientists to determine the causes of mass mortalities in the Middle Atlantic area has increased greatly during the past two years. An organism suspected as the causative agent has been discovered but not yet identified. The 1958 and 1959 year classes of oysters in Delaware Bay have survived better than earlier groups which may indicate that a resistant strain is being developed.

The fungus parasite *Dermocystidium* cannot be controlled as yet; however, certain measures can be taken to alleviate its effects. Oysters can be marketed at a younger age or transplanted to areas where this fungus is less common.

Seed shortages can be overcome by utilizing certain areas where reproduction is dependable to produce seed for other areas. This is already being done in certain places but private collection of seed could be expanded. Artificial propagation of seed oysters is now possible and may provide economic sources of seed in the near future.

Recent advances in our knowledge of chemicals may make it possible to control the mud shrimp in the Northwest. Preliminary experiments show that these species are easy to kill but further testing is required before control methods can be advocated.

Although causes of the oyster mortalities in the Northwest are not known at this time, it appears likely that the problem can be solved with sufficient effort.

While other problems such as high costs, low prices, and imports cannot be solved by biological research, production costs might be decreased by better growing, harvesting or processing techniques.

The Future

If we can look far enough ahead we can see a bright future for the oyster industry after today's problems are solved. This will not be the oyster industry which we know at present for it will use new methods and techniques and new areas for oyster production. Consider the future in four phases without setting a timetable for each phase.

First Phase

Oyster culture in the United States could be vastly improved if the best commercial practices in use today and the present scientific knowledge were applied throughout the industry. Production could be increased, quality could be improved, and costs could be lowered. The need for food for an expanding population should maintain high consumer demand for oysters.

During this period antiquated laws which hamper private enterprise would be corrected. Experience in Long Island Sound, Chesapeake Bay, and the Pacific Northwest has demonstrated the tremendous increase in production which can be achieved through private cultivation of oysters as compared with public management. During this period nearly all oyster-growing areas would be placed under private control but some seed areas might still be managed as a public resource.

Most predator control problems should be solved during this period by measures which, though expensive, could be used economically by private oyster farmers.

Causes of mass mortality would be discovered during this period and some control measures would be developed. It is unlikely that this problem could be completely solved during this period.

The oyster industry will face several serious problems during this period. Foreign competition will undoubtedly increase. The quantity and quality of oystering areas will decrease and production costs will continue to rise. The oystermen will be challenged to produce a product more acceptable to the consumer, more attractively packaged, of higher quality but without an undue increase in price.

Second Phase

Industrial development and increase in population in coastal areas will cause a continued decline in the quantity and quality of suitable environments for oyster culture during this second phase. The runoff of fresh water will decrease and the load of silt, domestic and industrial wastes carried by the rivers will increase. These factors will make it necessary to relocate that part of the oyster industry which is close to centers of population.

New culture methods such as the use of rafts placed in deep water away from cities will more than replace the areas which are no longer suitable for oystering. Handling, shucking and processing techniques will be improved to reduce costs. Already the Japanese raft culture technique produces 600 to 1,000 gallons of oyster meat on a raft 24 feet by 60 feet in eight months. This principle improved by modern materials and American mechanization will make it possible to compete economically with foreign imports.

Improved techniques for purifying oysters will be in common use to guarantee highest quality to the consumer.

Third Phase

A further decrease in natural areas suitable for oyster culture will make it necessary to grow oysters in ponds. Research on pond culture of oysters is already under way and methods should be perfected by this time. Seed oysters would be produced in private, commercial hatcheries following techniques which have recently been developed and which will be improved before this period. Our knowledge of nutrition will be advanced to the point that producing food for oysters will be possible and economically practicable. Selective breeding will increase growth rates, reduce disease, and improve flavor and other characteristics. Predators will be excluded and most diseases will be controlled.

Fourth Phase

The ultimate in oyster culture would be artificial propagation not dependent upon naturally clean sea water or natural food. The oysters might be grown under completely controlled environmental conditions in a few months. It is already possible to produce a continuous supply of phytoplankton under closely controlled conditions, and this method might be used to produce the oyster's favorite food. Perhaps "oyster pellets" or "instant oyster food" will be commercially available. Even now larval clams can be raised on dried foods at the U. S. Bureau of Commercial Fisheries Laboratory at Milford, Connecticut.

The water used in oyster culture might be taken from the ocean, diluted to the correct salinity and sterilized by ultraviolet light. Inland oyster farms might use artificial sea water which would be filtered, purified, and recirculated to maintain a perfect environment.

Oysters and other molluscs are among the most efficient sources of animal food since they feed directly upon plants. Their growth is rapid if food supplies are adequate and environmental conditions are satisfactory. Furthermore, the product is nutritious, well accepted and easily marketed. The prospects of increasing production of shellfish are extremely good; much better than the prospects of increasing quantities of other marine fishery products. Surely "Farming of the Sea" which we hold to be the solution to the food supply problem of the future will begin with culture of oysters and clams.

Predictions presented here are based on incomplete evidence and some unproven assumptions, but with faith in the ability of American scientists and the resourcefulness of American industry. Present problems can be solved and the future can be bright, but only if we obtain the knowledge which will be needed in the future.

41

Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 4, October, 1961
pp. 439–443

Food of the American Smelt in Saginaw Bay, Lake Huron

WILLIAM G. GORDON

Food of the American Smelt in Saginaw Bay, Lake Huron[1]

William G. Gordon[2]

U. S. Bureau of Commercial Fisheries, Biological Laboratory, Ann Arbor, Michigan

ABSTRACT

The food of 159 young-of-the-year American smelt (*Osmerus mordax*) and 256 I-group and older fish from Saginaw Bay was examined. Thirty-one stomachs from the first group and 35 from the second were empty. Collections were made by bottom trawl and gill nets at seven localities in depths of 2 to 26 fathoms on 11 dates from July 21 to November 1, 1956. The O-group smelt contained mostly crustaceans which were present in all stomachs that contained food. Copepods were taken more frequently than cladocerans. Other food items were Rotatoria, small unidentified eggs, and algal remains. Crustaceans, insects, and fish made up nearly all of the food of the I-group and older smelt. Mean percentage frequency of occurrence and percentage of total volume were: crustaceans, 71 and 36 percent; insects, 31 and 44 percent; fish, 8 and 20 percent. Most important crustaceans were cladocerans and *Mysis*, the predominant insect was *Hexagenia*, and all fish were young *Notropis* or smelt. Saginaw Bay smelt compete for food with young of all associated species and with the adults of some. They did not eat commercially exploited fish other than smelt.

INTRODUCTION

The spread of the introduced American smelt, *Osmerus mordax* (Mitchill), throughout the four upper Great Lakes (Van Oosten, 1937) and the increase of stocks in many waters to extremely high levels of abundance have given rise to questions concerning relations between this species and native fishes. It is particularly important to learn more of the role of the smelt as a competitor for food and as a predator on other fish. Studies of the food habits of smelt in the Great Lakes (Schneberger, 1937) do not indicate that the species is a predator of any consequence. Available information is limited, however, and many who are interested in the fisheries of the Great Lakes are convinced that this fish is an important predator of other species. Some believe that predation on lake trout fry by smelt was the major cause of the destruction of trout stocks in Lakes Michigan and Huron and the severe decrease of lake trout in Lake Superior. The present report on the feeding of smelt in Saginaw Bay is a contribution to our knowledge in the field. The author is grateful to the crew of the Bureau of Commercial Fisheries research vessel *Cisco* for aid in collection of data. The constructive criticism and advice offered by Ralph Hile are acknowledged.

MATERIALS AND METHODS

The present study is based on 424 smelt stomachs collected at seven localities on 11 dates over the period July 21–November 1, 1956. One hundred and fifty-nine were young-of-the-year (O-group) and 265 were I-group fish and older (Table 1, Figure 1). All O-group smelt and most older fish were taken by bottom trawls, 39 feet wide at the head rope and 35 feet long. Mesh sizes (extension measure) were 2½ inches in the forward end, 1–2 inches in the after-belly, and ½ inch in the cod end. Smelt taken at stations 6 and 7 were caught by nylon gill nets. These fish were not actually gilled but were entangled in the webbing, mostly by their teeth.

Specimens were preserved whole in 10-percent formalin and the stomachs removed in the laboratory. Occurrence of various food items was recorded for individual stomachs, but the contents were so small that individual estimates of volume could not be made. For smelt older than age-group O, data on percentage volume have been based on pooled collections of all fish taken within single calendar months. Volume measurements were made with a sedimentation (centrifuge) tube graduated to 0.1 milliliter. Volumetric study of food of young-of-the-year was not attempted. Measurements of total length were made on preserved fish and corrected for shrinkage after preservation by the empirically determined factor, 1.018.

FOOD OF O-GROUP SMELT

Crustaceans were the principal food of young-of-the-year (Table 2). The only other

---

[1] Based on a thesis submitted for a Master of Science degree, School of Natural Resources, University of Michigan.

[2] Present address: Exploratory Fishing and Gear Research Base, U. S. Bureau of Commercial Fisheries, Ann Arbor, Michigan.

TABLE 1.—*Number of smelt stomachs collected in Saginaw Bay by date, location, depth, and type of gear*

[Location of stations shown in Figure 1]

Date 1956	Station number	Depth (fathoms)	Gear	Number of stomachs	
				0-group	Older
July 21	3	3–7½	Trawl	50	50
Aug. 7	5	10	Trawl	–	50
Aug. 8	6	13–20	Gill net	–	14
Aug. 11	2	2½–5	Trawl	48	24
Aug. 31	3	3–10	Trawl	–	36
Sept. 19	5	6½–8	Trawl	30	28
Oct. 4	5	6½–11	Trawl	–	7
Oct. 9	4	3½–11	Trawl	–	12
Oct. 14	1	2–5	Trawl	31	–
Oct. 31	5	7–10	Trawl	–	9
Nov. 1	7	24	Gill net	–	35
Total	–	–	–	159	265

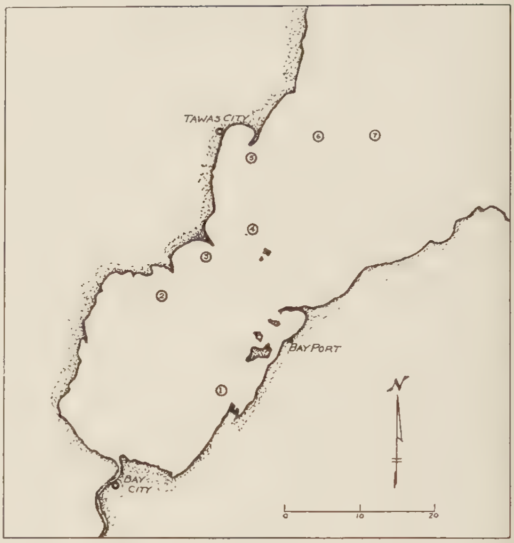


FIGURE 1.—Map of Saginaw Bay, Lake Huron, Michigan, showing location of the stations (circled numbers) at which smelt stomachs were collected.

items were Rotatoria, small unidentified eggs, and algal remains. Crustaceans were present in all stomachs that contained food. The copepods *Cyclops* and *Diaptomus* were most commonly taken and were about equally plentiful. The latter were taken less frequently than the former in August. Copepods of both genera appeared in fewer stomachs in September (33 and 29 percent) than in other months (44 to 88 percent).

The cladocerans, *Daphnia* and *Bosmina*, were eaten by young smelt of all four collections. Both were taken more frequently in September and October than in July and August, and all stomachs in the September sample contained *Daphnia*. *Holopedium* and *Alona* were eaten only in August and September and by small percentages (4 or 5 percent) of the fish.

The stomachs of young-of-the-year smelt contained Rotatoria in July and August only. *Keratella* was present in both months (7 and 5 percent) and *Kellicottia* in August only (8 percent). Small unidentified eggs were found in 3 of the 4 months (13 to 25 percent of the stomachs). Algal remains (often in dense mats) were eaten in all months, but the percentages were small (7 to 12 percent).

TABLE 2.—*Food of young-of-the-year (0-group) smelt expressed in percentage frequency of occurrence*

Item	Percentage frequency			
	July 21	Aug. 11	Sept. 19	Oct. 14
Number of stomachs	50	48	30	31
Number empty	8	10	6	7
Fish length (inches)	1.1–1.9	1.2–2.3	1.7–2.3	1.7–2.5
Depth (fathoms)	2½	2½	6½–8	3
Crustacea	100	100	100	100
Copepoda				
Cyclops	76	78	33	83
Diaptomus	78	44	29	88
Cladocera				
Daphnia	19	10	100	67
Bosmina	14	8	25	42
Holopedium	–	5	4	–
Alona	–	5	4	
Rotatoria	7	13	–	–
Keratella	7	5	–	–
Kellicottia	–	8	–	–
Small eggs	17	13	–	25
Algal remains	7	8	8	12

Only limited data have been published concerning the food of young smelt. Greene (1930) found copepods, cladocerans, rotifers, and algae in small smelt collected in lakes of the Champlain watershed, New York, during the summer. In other published studies food of the large and small fish were not separated.

FOOD OF I-GROUP AND OLDER SMELT

The food of I-group and older smelt was almost exclusively crustaceans, insects, and fish (Tables 3 and 4). The only other items, Hydracarina and debris, occurred in trivial frequencies and amounts. Crustaceans were eaten most frequently; insects made up the greatest bulk of food; and fish, although present in few stomachs, made up a substantial percentage of the total diet.

Crustaceans were most prominent in the diet in July, October, and November when the percentage frequency ranged from 86 to 100 percent and the percentage volume from 25 to just under 100 percent. They were less common in August (frequency, 57 percent; vol-

TABLE 3.—*Food of age-group I or older Saginaw Bay smelt expressed in percentage frequency of occurrence and (in parentheses) percentage of total volume for each food item*

[Less than 0.5 is indicated as a trace (tr)]

Item	Percentage frequency				
	July 21	Aug. 7, 8, 11, and 31	Sept. 19	Oct. 4, 9, and 31	Nov. 1
Number of stomachs	50	124	28	28	35
Number empty	15	13	7	0	0
Fish length (inches)	2.3–5.3	2.3–7.4	3.8–7.5	5.5–7.3	5.8–7.3
Depth (fathoms)	2½–7½	4–16	6½–8	3½–11	26
Crustacea	86 (25)	57 (14)	19 (4)	95 (37)	100 (100)
Copepoda					
Diaptomus	–	8 (tr)	7 (tr)	17 (tr)	–
Cyclopidae	20 (tr)	–	–	–	–
Cladocera					
Daphnia	52 (25)	22 (11)	4 (tr)	92 (34)	–
Alona	12 (tr)	–	–	17 (2)	–
Unidentified	–	13	6	–	–
Ostracoda	–	15 (tr)	–	8 (1)	–
Mysidacea					
Mysis	–	–	–	–	100 (100)
Amphipoda	–	6	–	–	–
Pontoporeia	–	4 (tr)	4 (4)	–	3 (tr)
Gammarus	–	4 (tr)	–	–	–
Arachnoidea					
Hydracarina	–	2.4 (tr)	–	–	–
Insecta	8 (50)	71 (59)	58 (46)	17 (63)	–
Ephemeroptera					
Hexagenia	2 (42)	14 (25)	45 (40)	17 (63)	–
Ephemera	2 (4)	2 (6)	4 (3)	–	–
Diptera					
Tendipedidae	4 (4)	51 (8)	–	–	–
Unidentified	–	2 (tr)	9 (3)	–	–
Remains	4 (tr)	7 19	–	–	–
Fish	8 (25)	7 (27)	23 (49)	–	2 (tr)
Smelt (young)	–	–	23 (49)	–	–
Notropis spp.	8 (25)	6 (27)	–	–	–
Remains	–	2 (tr)	–	–	2 (tr)
Debris	–	–	–	–	8 (tr)

ume, 14 percent) and relatively unimportant in September (frequency, 19 percent; volume, 4 percent). The significance of the dominance of crustaceans in the November 1 sample is questionable since these fish were caught in such deep water that their stomach contents may not be compared with those of fish caught at lesser depths in other months.

Cladocerans made up the bulk of the crustaceans, except in November when the smelt of the deep-water sample had eaten *Mysis* almost exclusively. *Daphnia* was far more important than *Alona* which was consumed in small amounts and only in July and October. Copepods were eaten in every month but November, ostracods in 2 months, and amphipods in 3 months, but at no time did the rate of occurrence exceed 20 percent (copepods in July) or the percentage volume 3 percent (amphipods in September).

Insects made up at least half the food volume in 3 of the 4 months in which foods other than Crustacea were eaten and in the fourth month (September) accounted for 46 percent of the total. The percentage frequency ranged widely from only 8 percent in July (volume, 50 percent) to 71 percent in August.

The mayfly genus *Hexagenia* strongly dom-

TABLE 4.—*Percentage frequency of occurrence and percentage of total food volume for major food categories of Saginaw Bay smelt, age-group I and older, 1956*

Item	Percentage value for month					
	July	August	September	October	November	Average[1]
Crustacea						
Percentage occurrence	86	57	19	95	100	71
Percentage volume	25	14	4	37	100[2]	36
Insecta						
Percentage occurrence	8	71	58	17	0	31
Percentage volume	50	59	46	63	0	44
Fish						
Percentage occurrence	8	7	23	–	2	8
Percentage volume	25	27	49	–	0[3]	20

[1] Unweighted.
[2] More than 99.5.
[3] Less than 0.5.

inated the insect food of the Saginaw Bay smelt during the 4 months insects were found in stomachs. This form regularly made up the bulk of the identifiable insect material and in individual months contributed 25 to 63 percent of the total food volume. The percentage representation varied from 2 percent in July, when the contribution to the total diet was 42 percent, to as high as 45 in September, when *Hexagenia* contributed 40 percent of the total food. The mayfly *Ephemera* was taken in 3 months, but the contribution to the total food volume did not exceed 6 percent. Dipterans were consumed only in July and August. In the latter months they were present in 51 percent of the stomachs but made up only 8 percent of the total food volume.

Consumption of fish by smelt was confined almost entirely to the 3-month period, July–September. The percentages of total volume in these months were 25, 27, and 49, and the percentages of stomachs containing fish were 8, 7, and 23. All identifiable fish belonged to the minnow genus *Notropis* in July and August, and all were young smelt in September. No stomach contained any commercially exploited species other than smelt. The incidence of fish in the stomachs was greater among large than among small smelt.

The observations on the food of Saginaw Bay smelt agree with the findings of Schneberger (1937) on the smelt of Green Bay, Lake Michigan, in that the smelt of both areas subsisted mainly on invertebrates and consumed more of their own species than of any other kind of fish. The two series of samples did, however, show considerable difference of detail. In Green Bay the most important food item, by a wide margin, was *Mysis*, found only in the deep-water collection of November 1 from Saginaw Bay. On the other hand, *Hexagenia*, a form of major importance in Saginaw Bay, had been consumed by few smelt in Green Bay. Fish other than smelt eaten in Green Bay were *Cottus* and the burbot, *Lota lota*. Most of the differences between the diets of smelt in the two areas probably can be attributed to differences in the availability of food items at the time, place, and depth of collection. Available evidence indicates that the smelt is a versatile feeder.

SMELT AS A COMPETITOR AND PREDATOR

The almost total dependence of young-of-the-year smelt of Saginaw Bay on crustaceans and the predominance of insects and crustaceans in the diet of older fish show that the species is a competitor of the young of all associated species and of the older individuals of many. Detailed appraisal of the smelt as a competitor for food in Saginaw Bay is not possible because there is insufficient information on the food habits of the various fishes. Published records are available only for yellow perch (Tharratt, 1959). The comparison of Tharratt's records with those of the present study reveals that perch and smelt do consume many food items in common. A similar situation probably holds for other species.

Adverse effects of food competition by smelt on other species depend on a rate of consumption so great that a food scarcity develops. The heavy runs of smelt in tributary streams and the experimental fishing by the research vessel *Cisco*[3] indicate that the population is large, but there is no evidence of adverse effects on other species. El-Zarka (1959) pointed out that the assumption of a food scarcity for Saginaw Bay perch in recent years was not tenable since fish collected in 1943–55 averaged heavier, length for length, than did perch collected in 1929–30 (before smelt became plentiful in the bay).

The present study, like the earlier (1937) investigation by Schneberger in Green Bay, failed to indict the smelt as a significant predator on commercially exploited species, except possibly the smelt itself.

---

[3] Carr, Ira A. (MS) Distribution and seasonal movements of Saginaw Bay fishes.

LITERATURE CITED

El-Zarka, Salah El-Din. 1959. Fluctuations in the population of yellow perch, *Perca flavescens* (Mitchill), in Saginaw Bay, Lake Huron. Fish. Bull., U. S. Fish and Wildl. Serv., 59: 365–415.

Greene, C. Willard. 1930. The smelts of Lake Champlain. Pt. IV, Biol. Surv. Champlain Watershed. Suppl. 19th Ann. Rept., N. Y. Cons. Dept. (1929): 105–120.

Schneberger, Edward. 1937. The biological and economic importance of the smelt in Green Bay. Trans. Am. Fish. Soc., 66: 139–142.

Tharratt, Robert C. 1959. Food of yellow perch, *Perca flavescens* (Mitchill), in Saginaw Bay, Lake Huron. Trans. Am. Fish. Soc., 88: 330–331.

Van Oosten, John. 1937. The dispersal of smelt, *Osmerus mordax* (Mitchill), in the Great Lakes region. Trans. Am. Fish. Soc., 66: 160–171.

REPRODUCTIVE BEHAVIOR OF NORTH AMERICAN STICKLEBACKS

42

By Wilbur L. Hartman
Brooks Lake Laboratory
King Salmon, Alaska

kground:

Some of the most interesting and fundamental research on fish
avior has been done in Europe by N. Tinbergen and his students
the three-spined stickleback, *Gasterosteus aculeatus*. Many of
ir results have added considerable insight into the broad study
animal behavior. Early detailed observational research was fol-
ed later by experimental research on the causal structure under-
ng the reproductive behavior. Fish models and other props were
d to determine environmental factors that may act as sign stim-
and serve to release behavior patterns at different times dur-
the reproductive cycle.

It would be valuable to study, in addition, the reproductive
avior of North American species, *Pungitius pungitius*, the nine-
ned stickleback; or *Eucalia inconstans*, the five-spined stickle-
k, for comparison with the European species. It would be of
ther value to see if the same sign stimuli determined for the
opean three-spined species would release similar behavioral re-
nses in North American species. Such a study should give a
stantial introduction to literature search and opportunity for
ervational and experimental research.

lem:

The basic problems involve describing the reproductive be-
ior of a North American species of stickleback and also compar-
the effects of sign stimuli on this species with information
the European three-spined species. This problem involves five
ges: (1) review of literature on stickleback behavior and sign
muli, (2) establishment of a successful aquarium, (3) observa-
nal study of reproductive behavior, (4) experimental study of
n stimuli, and (5) analysis of data and preparation of a report.

cial Considerations:

Keep detailed records throughout the establishment of the
arium and the observational and experimental research. Measure
record major factors of the environment such as light and water

temperature. Try regulating them experimentally. Still and motion photography could be used for review and documentation. As a final caution, make several trials with several different sets of fish to establish any indication of "average" behavior and its variations.

References:

General

1. Scott, J. P. Animal Behavior. Univ. Chicago Press, 1958.

2. Tinbergen, N. The Study of Instinct. Oxford Univ. Press, 1951.

Specific

3. Craig-Bennett, M. A., 1931. The reproductive cycle of the three-spined stickleback, Gasterosteus aculeatus Linn. Philos. Trans. Royal Soc., London, series B, 219:197-279.

4. Greenbank, J. and P. R. Nelson, 1959. Life history of the three-spined stickleback, Gasterosteus aculeatus Linnaeus, in Karluk Lake and Bare Lake, Kodiak Island, Alaska. U. S. Fish and Wildlife Service, Fishery Bull., 153, 59:537-559.

5. Tinbergen, N., 1942. An objective study of innate behavior of animals. Biblioth. Biotheor., 1:39-98.

6. Tinbergen, N. and J. J. A. van Iersel, 1947. 'Displacement reactions' in the three-spined stickleback. Behavior. 1:56-63.

7. Vrat, V., Reproductive behavior and development of the three-spined stickleback (Gasterosteus aculeatus) of California. Copeia, 1949(4):252-260.

Made in the United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 1, January, 1961
pp. 6-12

Regular Occurrence of False Annuli in Four Brook Trout Populations

RICHARD W. HATCH

Regular Occurrence of False Annuli in Four Brook Trout Populations

Richard W. Hatch[2]
Department of Conservation, Cornell University, Ithaca, New York

ABSTRACT

False annuli were found in 65 to 90 percent of brook trout (*Salvelinus fontinalis*) specimens of several year classes sampled in four Adirondack lakes. Maximum age of fish present was known since all four lakes were recently reclaimed. One or two false annuli were found on scales of trout planted as advanced fry or hatched from eggs deposited naturally. A method of identifying accessory checks based on scale measurements was developed for determining age of these trout. Influence of environmental temperature on growth rate is discussed as a possible explanation for formation of false annuli.

INTRODUCTION

Age determinations based on scale studies have become so widely used by fishery biologists that certain scale characteristics may often be accepted as annular markings without further study. Validity of annuli may be established by comparing age distributions taken from scale studies to length-frequency distributions for the same populations, but unless known-age fish are available, it is seldom possible to validate annuli with certainty. Information on accessory checks in brook trout has received little notice in recent literature on age and growth. Cooper (1951) mentions two instances of false annuli on trout from Michigan streams. Allen (1956) validated annuli on scales of brook trout from a Wyoming beaver pond without encountering false annuli. Alvord (1954) validated only those annuli formed between tagging and recapture. He attributes occasional formation of checks to trauma in original capture and handling while tagging.

An age-and-growth study on brook trout, *Salvelinus fontinalis* (Mitchill), in four recently reclaimed Adirondack lakes revealed the regular formation of false annuli in all four trout populations. East Lake, Panther Lake, and Upper and Lower Sylvan Ponds are located in Herkimer County, New York. Morphometric, physical, and chemical features of these waters are summarized in Table 1. Semiannual inventories of trout populations in these waters were carried out from 1955 to 1958 in connection with production studies. Trap and gill nets, fixed stream traps, and electrofishing gear were used to collect material. Scale samples were taken from the caudal peduncle below the adipose fin. Scales were either mounted in water under a cover glass or impressed on cellulose acetate for study. All readings and measurements were taken on a back-projection device at a magnification of 84.65 diameters. Scale measurements recorded herein are those of the magnified scale image.

Annular characteristics of brook trout scales listed by Cooper (1951), which included sudden change in growth pattern of circuli characterized by crowding followed by wide spacing, irregular or incomplete circuli, and crossing over in lateral fields, were used to define annuli. Scale configurations which conformed to these characteristics were regarded as checks until they were validated as annuli.

OCCURRENCE OF FALSE ANNULI ON SCALES

East Lake

East Lake was reclaimed with rotenone in October 1954 and restocked with advanced fry (1 inch) and fin-clipped yearling brook trout in May 1955. Fin-clipped fingerlings have been stocked annually in the fall since September 1955. Considerable numbers of naturally produced trout of the 1956 and later year classes are also found in the population. Early in the study of East Lake trout scales, it became apparent that false annuli were being formed with considerable regularity. In 1956, 70 and 65 percent of scales read from East Lake in spring and fall samples, respectively, indicated that trout of age-groups II and III were present, but only age-groups 0 and I were actually available. The 1955 year class was the only group of unmarked fish that was completely vulnerable to trap-net sampling throughout 1956. The 1956 year class was not vulnerable to sampling except by stream traps in the fall of 1956. Reclama-

---

[1] Based on part of a doctoral dissertation submitted to the faculty of the Graduate School, Cornell [illegible]

[2] Bureau of Commercial Fisheries Biological Laboratory, Juneau, Alaska.

Table 1.—*Morphometric, physical, and chemical characteristics of four Adirondack lakes from which trout were taken*

Measurement	East Lake	Lower Sylvan Pond	Upper Sylvan Pond	Panther Lake
Area (acres)	31.9	16.8	12.2	41.6
Maximum depth (feet)	36	18	33	20
Mean depth (feet)	14.3	9.4	12.7	11.0
Average pH	7.0	6.8	6.8	7.1
Total alkalinity (p.p.m.)	8.2	3.0	3.3	8.6
Summer stratification	Yes	No	Yes	No
Secchi-disk depth (feet)	12	18	21	20
Tributary streams	2	1	0	0

tion was considered to be completely successful in the lake since only a single minnow has been seen in East Lake during the 5 years following treatment. Before reclamation, bullheads (Ictaluridae), suckers (Catostomidae), and minnows (Cyprinidae) dominated the lake fish fauna. Trout eggs already in the gravel in a tributary of the outlet at the time of reclamation survived, but trout hatching from these eggs would belong to the 1955 year class and would appear as age I in 1956. The problem of defining true and false annuli is discussed in detail for trout from East Lake because large samples are available. Further examples of false annulus formation are then demonstrated in the other three waters studied.

The numbers of checks found on scales of trout of various sizes in the 1955 year class during three sampling periods in 1956 are shown in Table 2. Only the smallest fish in the May sample failed to show checks. In the summer sample, all fish showed one check and 85 percent showed two checks. In the fall sample, 34 percent showed one check, 49 percent two checks, and 17 percent three checks although these fish were not more than age I+.

Table 2.—*Frequency of occurrence of checks in spring, summer, and fall samples of 1955 year class trout taken from East Lake in 1956*

[Summarized by total length groups]

Total length (nearest inch)	No checks	One check	Two checks	Three checks
Spring				
4	11	6	0	0
5	0	0	0	0
6	0	3	0	0
7	0	11	1	0
8	0	6	0	0
9	0	1	0	0
Summer				
5	0	1	1	0
6	0	0	3	0
7	0	0	4	0
8	0	2	8	0
9	0	0	0	0
10	0	0	1	0
Fall				
5	0	9	0	0
6	0	13	6	0
7	0	15	25	0
8	0	0	14	4
9	0	0	5	9
10	0	0	3	5

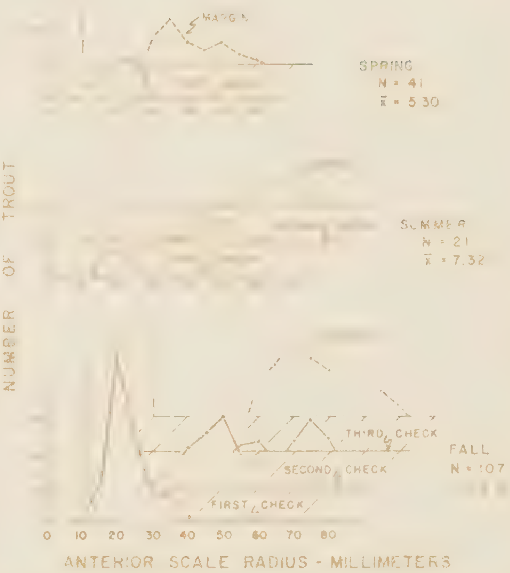


Figure 1.—Formation of checks on scales of 1955 year class, East Lake. Frequency of occurrence of first, second, and third checks in 5-millimeter intervals from center of scale focus indicated in three samples taken in 1956. Sample size indicated by N; mean total length by $\bar{x}$.

Frequency of occurrence of checks along the mid-anterior scale radius was plotted (Figure 1) to determine which checks were true annuli and which represented only a change in growth during the year. The May sample (taken 1 week after ice cover broke up) showed that the scale margin at the beginning of spring growth was rarely less than 20 millimeters from the center of the focus. Location of the scale margin in the 1956 year class sampled in the fall of 1956 supported this observation (Figure 2). In this sample (98 trout) nine fish had scale margins less than 20 millimeters from the center of the focus, and two had margins less than 18 millimeters from the center. Three of the nine fish had a check well within the margin. It appears, therefore, that formation of a true annulus less than 20 millimeters from the center of scale focus was seldom possible in the 1955 year class.

In the 1956 year class, a true annulus could seldom occur less than 18 millimeters from the

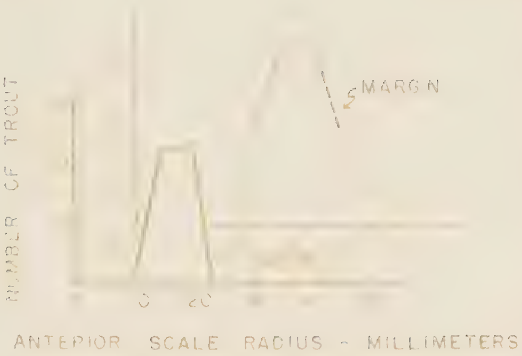


FIGURE 2. Distribution of check and margin on scales of 1956 year class, East Lake, sampled by stream traps, November 1956. N = 98, x = 4.35 inches.

center of the scale focus. Any annulus-like pattern less than 20 millimeters from the focus in the 1955 year class, or less than 18 millimeters from the focus in the 1956 year class, must therefore be interpreted as an accessory growth check. A pictorial record of formation of checks and annuli on scales of the 1955 year class in East Lake is shown in Figure 3. Age designation for each scale is the oldest that could be attained by the first trout stocked after reclamation. Figure 3A shows a check on a scale taken in fall 1955, 5 months after initial stocking of advanced fry. An accessory check is also clearly visible in Figure 3C. Figure 3B shows a trout scale of the same age and taken at the same time as the one in Figure 3C, but without a check.

The first true annulus is shown in Figure 1, summer sample. In this and in the fall sample, distribution of the second check corresponded well with the distribution of scale margins in May. The second check, therefore, was regarded as the true annulus on all fish showing more than one check in fall 1956. Both the check and annulus are shown in Figure 3D. The distributions of first and second checks overlap (Figure 1). The first check was regarded as the true annulus on fish showing only this mark (Figure 3F) unless it was less than 20 millimeters from the focus. These fish were the smallest sampled in May, which showed no check (Table 2, Figure 3B). Occurrence of an accessory check in scales of the 1956 year class (Figure 2) indicates formation of a check was not peculiar to a particular year class or growing season. In this case, also, location of the check on larger

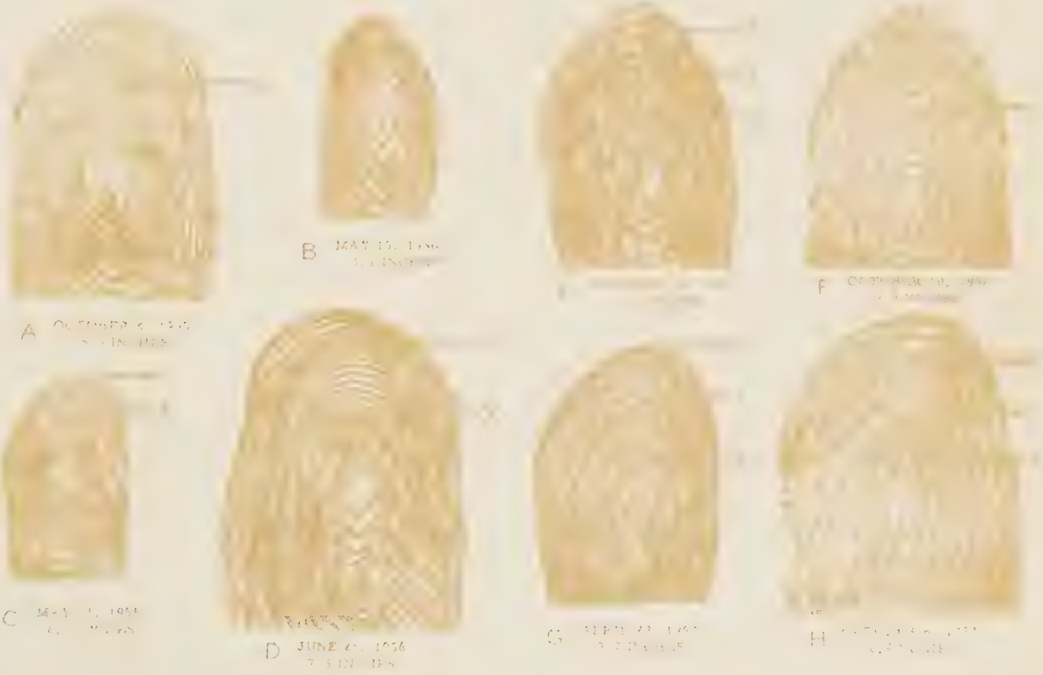


FIGURE 3. Scales of East Lake brook trout of the 1955 year class (X 38). True annuli indicated by Roman numerals, false annuli (checks) by X. Date of capture and total length at capture indicated below each scale photograph.

scales overlapped location of the margin on smaller scales. A second accessory check on scales of some members of the 1955 year class (Table 2, Figure 3E) is close to the margin in 1956 samples and is not as clear as the check formed during the first growing season. It would ordinarily be regarded as an annulus only if the population in question were known to have a very low growth rate.

There was some difficulty in separating the 1955 and 1956 year classes in 1957 samples. Many members of the 1956 year class had checks at a 20-millimeter radius from the scale focus (Figure 2). Most members of this group had scale margins 30 millimeters or less in radius in fall 1956. The true annulus in this group should, in general, be 30 millimeters or less from the scale focus. Annuli less than 30 millimeters in radius were rare in the 1955 year class (Figure 1).

The procedure of age determination adopted for use with 1957 samples involved measurement of distance of various checks from the scale focus at 85 diameters magnification. Any check less than 18 millimeters from the center of the focus was rejected as an accessory check, and age was assigned accordingly. Ages were assigned to other trout according to the following key for scale measurements:

A. Only two checks present, both less than 30 millimeters from center of scale focus . . . . . 1956 year class

AA. Two or more checks present; if only two, one more than 30 millimeters from center of scale focus . . . . . B.

  B. First check less than 20 and second more than 30 millimeters from center of scale focus (comparatively rare) . . . . . 1956 year class

  BB. First check more than 20 and second more than 30 millimeters from center of scale focus . . . . . 1955 year class

This system undoubtedly produced some misclassifications. Since both the inner accessory check and first annulus fulfilled the description of an annulus, it was necessary to set up these arbitrary rules for deciding age in individual cases. Age distributions of East Lake fish resulting from this procedure are presented in Hatch and Webster (in press).

Further sampling in East Lake streams during 1958 showed a similar pattern of development of scale characters in the 1958 year class. A sample was taken in July from a stream trap near the mouth of the lake inlet. Additional samples were taken by electrofishing in August, September, and November from the mouth to a point about 200 yards upstream.

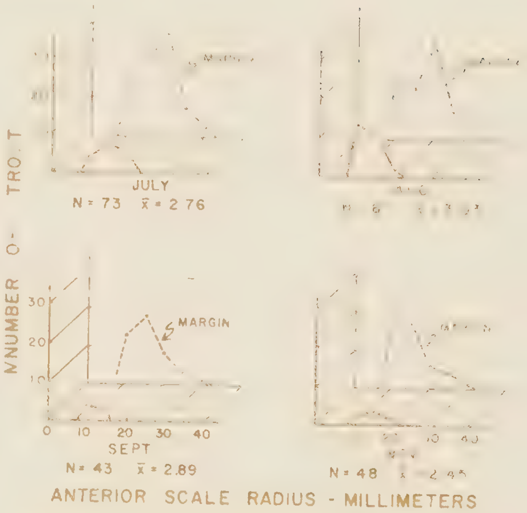


FIGURE 4.—Development of scale characters of 1958 year class, East Lake, as shown by four samples taken during 1958.

Some fish in these samples (Figure 4) had an accessory check on the scales varying between 10 and 20 millimeters from the focus. Since scale measurements did not increase in later samples, absence of growth was indicated. Mean length of trout sampled in September and November was less than mean length in August. Presumably this apparent lack of growth was a result of continuous movement of larger fish from stream to lake throughout the summer. Five percent of 140 fish taken in July and August (1.3 to 1.9 inches total length) had not yet formed scales, but even the smallest of 43 trout taken in September (1.7 inches) had scales. No scales less than 8 millimeters in radius were seen.

Sylvan Ponds

Upper and Lower Sylvan Ponds are connected by a short stream. Both were reclaimed in October 1952 and restocked with advanced fry in June 1953. Additional plantings of advanced fry were made in 1954 and 1955. Finclipped fall fingerlings were planted in 1955 and 1956.

Regular formation of false annuli also took place in trout from the Sylvan Ponds. Three scale samples taken in Lower Sylvan Pond in October 1953, 4 months after initial restocking, showed checks within the margin. Scales were taken from 18 trout in the Sylvan Ponds in 1954. At least two checks were found in 85 percent of these samples, although age I+ was the oldest age possible in 1954. Scale

studies of fall 1955 samples showed that 92 percent of fish taken in both Sylvan Ponds had at least two checks within the margin (37 percent of those from Lower Sylvan Pond had three).

Age II+ trout could have been present in the Sylvan Ponds in 1955, but not in the frequency suggested by the fall samples. Growth in the Sylvan Ponds, particularly in Lower Sylvan Pond, is faster than in East Lake. A sample of yearlings from Lower Sylvan Pond in fall 1954 had a mean length of 10.5 inches, indicating that the 1953 year class was completely vulnerable to angling in 1955 and mostly vulnerable in 1954. Of 20 tags placed in this sample, five were recovered by anglers in 1955, indicating that the 1953 year class was heavily harvested prior to the inventory in fall 1955. Only three of these tags were recovered in 1956 (two in spring trap netting, one by angling) and none since that time. This evidence suggests that the majority of trout sampled by nets in fall 1955 and spring 1956 were members of the 1954 year class. One of the checks on the scales of this group must again be regarded as a false annulus.

Distribution of inner checks along the anterior scale radius in Sylvan Ponds' trout was quite similar to that for East Lake. Since it was not possible to sample fish less than 6 inches long adequately in these waters, a lower limit could not be set for scale margins at the end of the first growing season. The smallest fish taken in stream samples (6 inches) had scale margins at least 30 millimeters from the center of the scale focus. It is therefore assumed that, as in the slower growing East Lake population, any annulus-like check less than 20 millimeters from the focus must be an accessory check; and that marks between 20 and 25 millimeters would be subject to question. Fish whose scales fall into the latter category were extremely rare in Upper Sylvan Pond and made up less than 20 percent of the samples in Lower Sylvan Pond. They were placed in the appropriate age groups on the basis of total length compared with the distribution of lengths of fish in which age was assigned without this difficulty. Satisfactory age structures were derived for these populations using the criteria outlined above (Hatch and Webster, in press). A second accessory check was sometimes formed during the second growing season and occurred quite frequently in fish from Lower Sylvan Pond but only occasionally in those from Upper Sylvan Pond.

Panther Lake

Panther Lake was reclaimed in fall 1951 and restocked with yearlings and fingerlings in 1952. Fingerlings were planted in 1953 and advanced fry in 1954. Fin-clipped fall fingerlings were planted in 1955 and 1956. No unclipped fish have been stocked since those representing the 1954 year class. Unclipped fish of later year classes are the result of natural reproduction and are relatively few in number. Accessory checks formed during the first growing season would be expected to appear only in the 1954 year class as a whole and in naturally spawned members of other year classes. This appears to be the case, since an annulus-like mark less than 20 millimeters from the scale focus occurs mainly in a large group (interpreted as the 1954 year class) and in two smaller groups (interpreted as naturally produced members of the 1955 and 1956 year classes) which can be followed throughout the study on the basis of length-frequency distribution. A pronounced check corresponding to summer 1955 appears on scales of fish judged to belong to the 1953 and 1954 year classes. This check is believed to have resulted from a suspension of growth during late July and early August 1955, when very hot weather brought temperatures to the lethal level for brook trout (Webster, 1956[3]). With the exception of these two checks, annuli were accepted as true year marks on scales of Panther Lake brook trout.

FORMATION OF FALSE ANNULI

The accessory check fulfills all criteria for annuli and must, therefore, represent a change in growth rate. Temperature is an important factor which influences growth rate in fish. Fry,[4] summarizing knowledge on relation of temperature to growth in brook trout, indicates that optimal growth range is between 55° and 60° F. Baldwin (1957), studying gain in weight of brook trout at five temperatures, shows fastest growth at 55.4° F. and slowest growth at 69.8° F. Graham (1949) found that activity of brook trout decreases rapidly above 68° F. A change in environment that removes trout from their optimal

---

[3] Webster, D. A. (1956) Fishery management report for 1955. Adirondack League Club. 26 pp. (Multi.).

[4] Fry, F. E. J. (1951) Some environmental relations of the speckled trout (*Salvelinus fontinalis*). Repr. from Proc. N. E. Atlantic Fish. Conf., 29 pp. (Mimeo.).

growth range could cause a change in growth that might be reflected in the scales as a check.

Summer surface temperatures generally exceed the optimum range in all four lakes. Lower Sylvan Pond and Panther Lake remain homothermous throughout summer, and water temperatures exceed 70° F. for long periods during most summers and occasionally approach 80° F. The waterway between Upper and Lower Sylvan Pond is warm (usually only 1 or 2 degrees cooler than Lower Sylvan Pond itself) and is inhabited by only a few fingerling trout. The outlet of Lower Sylvan Pond is cooled by several springs that enter at some distance below the pond. This stream supports a substantial population of fingerling trout on a limited food supply and their growth is not rapid. Since a thermal block of warm water exists between the fingerling population and the lake environment during summer, fingerling trout (whether stocked as advanced fry or produced naturally) in Lower Sylvan Pond have two possible environments for the first summer.

There are two periods of optimum growth temperature during late spring and early autumn for fingerlings that remain in the lake. Between these two periods is an interval of summer temperatures above the range of optimum growth. These changes would be reflected on scales as a check between two periods of rapid growth. Cooper (1951) mentions formation of a similar false annulus in brook trout in a few Michigan streams after a midsummer rise in water temperature. Trout spending their first summer in the outlet to Lower Sylvan Pond and migrating upstream in early autumn as the lake temperature drops (a migration which has not been established) also would be likely to show a check resulting from increased growth in the richer lake environment. The production of such a mark ("stocking check" resulting from a rapid increase in growth following release which is often more prominent than the true annulus that follows) has been established in all plantings of fin-clipped fall fingerlings made in these ponds.

Panther Lake has no tributaries or outlet utilized by fingerling trout. The outlet is warm, and a small cold spring entering the lake is inhabited only by advanced fry. Planted fry or naturally produced trout in this lake may also show a check suspected to be a false annulus resulting from midsummer decrease in growth rate because there are high water temperatures. The strong check noted on scales of Panther Lake trout following the hot summer of 1955 is an example.

A different explanation must be sought for the formation of checks in scales of trout from East Lake and Upper Sylvan Pond. Both of these lakes provide cool water in the hypolimnion which is available for summer retreat of trout when surface temperatures become too high. East Lake also has two spring-fed tributaries that remain in the optimal temperature zone of growth. Large numbers of advanced fry planted in East Lake in 1955 are known to have ascended the cool tributaries during the first warm period of early summer. Food supply in these tributaries was probably insufficient to support maximum growth rate in a large fingerling population. Similar conditions exist in the lake outlet. Trout of this planting that returned to the lake in late summer and early fall would probably show an increase in growth (Figure 3A) on returning to a habitat in which temperature and food supply favored optimum growth rate. Fish that did not pass downstream until spring 1956 would show no sharp change in growth during the first year (Figure 3B). A similar sequence of events could apply to naturally spawned members of the 1956 year class hatched in the stream system of East Lake. Trout of this year class that move downstream into the lake early in the first year would show two periods of rapid growth (spring and fall), while those that remain in the stream until late fall or the second spring would show only one period of rapid growth (first spring).

There are no data available from this study to describe the effect of vertical descent into deeper and cooler waters in the thermally stratified lakes (East Lake and Upper Sylvan Pond). Scales with no false annuli and with the first annulus well out from the focus presumably represent a life-history pattern of continuous lake growth. Some trout from Upper Sylvan Pond that show an accessory check may be immigrants from Lower Sylvan Pond. Tagging studies have established the fact that some mixing of populations takes place between the two ponds, but this mixing is probably not sufficiently great to account for all the false annuli observed in Upper Sylvan Pond trout scales.

High incidence of false annuli formed during the first year of life in the four populations studied has led to some doubt concerning procedures used in aging similar popula-

tions in nearby waters. Brook trout populations naturally produced or resulting from plantings of advanced fry must be carefully studied before any scale patterns are accepted as valid annuli.

ACKNOWLEDGMENTS

Dr. Dwight A. Webster of Cornell University gave advice and aid in conducting this study and reviewed the manuscript. Data recorded prior to 1956 were provided by him. This study was supported by the Adirondack League Club on whose property the lakes are located. Drs. W. L. Hartman, P. C. Neth, and E. W. Shell; and Messrs. B. E. Brown, G. S. Little, R. E. Vincent, and W. D. Youngs assisted in the sampling program. Drs. Hartman, C. J. DiCostanzo, and N. J. Wilimovsky and Mr. T. R. Merrell have critically reviewed the manuscript.

LITERATURE CITED

ALLEN, G. H. 1956. Age and growth of the brook trout in a Wyoming beaver pond. Copeia, 1956 (1): 1-9.

ALVORD, W. 1954. Validity of age determinations from scales of brown trout, rainbow trout, and brook trout. Trans. Am. Fish. Soc., 83: 91-103.

BALDWIN, N. 1957. Food consumption and growth of brook trout at different temperatures. Trans. Am. Fish. Soc., 86: 323-328.

COOPER, E. L. 1951. Validation of the use of scales of brook trout, *Salvelinus fontinalis*, for age determination. Copeia, 1951 (2): 141-148.

GRAHAM, J. M. 1949. Some effects of temperature and oxygen pressure on the metabolism and activity of the speckled trout, *Salvelinus fontinalis*. Canadian Jour. Res., D., 27: 270-288.

HATCH, R. W., AND D. A. WEBSTER. (In press.) Trout production in Adirondack waters. Memoirs Cornell Univ. Agr. Expt. Stat., Ithaca, New York.

and other species of salmon are found in lesser abundance. In 1959 the fishermen of Canada and the United States jointly took 4,167,000 pounds of halibut from the Bering Sea. The catch of this species by the Japanese and Soviet fishermen is unknown, but probably smaller. Although we have taken king crab in the southern Bering Sea, our fishery has dwindled, apparently from economic causes rather than a lack of crabs. The Japanese packed (1959) 70,000 cases of crab in this area, and the Russians also fished, although their catch is believed to have been much less.

The 1959 catch of bottom fish (chiefly cod, sole, and pollock) from the eastern Bering Sea was taken by Japan and the U. S. S. R. It was produced in the waters between the Pribilof Islands, which lie in the southeastern Bering Sea, and the American mainland. Japan took 350,000,000 pounds and the U. S. S. R. is estimated to have caught 150,000,000 pounds, or a total of about one-half billion pounds.

A whale fishery by Japanese and Russians takes place along the Aleutian chain. The catch by Japan in 1958 yielded about 400,000,000 pounds of meat, oil, and by-products.

About 60,000 fur seals are harvested annually by the United States under a treaty with Canada, Japan, and the U. S. S. R. The proceeds are divided among the United States, Canada, and Japan by agreement.

There appears to be vigorous competition for fish and crabs developing between the Japanese and the Russians in the Bering Sea. A possible outcome will be an early expansion of these operations to the waters of the Gulf of Alaska.

BIOLOGICAL RESEARCH AND THE ECONOMICS OF COMMERCIAL FISHERIES IN ALASKA

M. L. Hayes, U. S. Fish and Wildlife Service
Bureau of Commercial Fisheries, Juneau, Alaska

A major function of the fishery research biologist is to define biological productivity of the fishery and thus delimit yield in biological terms. The conversion of yield into political, social, and economic values is regulated by the management agency.

Yield information is supplied from knowledge of the population dynamics of the species in question. This information may consist of a subjective series of plus and minus considerations based on biological knowledge, or it may consist of more formal yield equations derived from mathematical models of fish populations.

Three mathematical methods of yield prediction were considered for application to Alaska's commercial fisheries. In its present state of development the analytical model of Beverton and Holt is limited in application to some bottomfish, halibut, and possibly king crab. The reproduction-curve approach formalized by Ricker has been widely applied to salmon and may have general application where necessary statistics on reproduction are available. Schaefer's method, which uses the logistic population growth curve, may provide first approximations to yield before adequate analytical data become available.

It was concluded that biological research has not yet provided adequate yield information for optimum utilization of the fishery resources of Alaska. But rapid advance toward this goal is to be anticipated with more extensive application of techniques based upon use of mathematical models.

CURRENTS IN SOUTHEASTERN BERING SEA

by
James F. Hebard
Biological Laboratory, Bureau of Commercial Fisheries
Seattle, Washington

ABSTRACT

During an investigation of the tidal and average currents in southeastern Bering Sea, carried out in June 1957, the currents were observed at four anchor stations by means of an Ekman current meter. Dextrally rotating tidal currents occurred on the two offshore stations, and greatly compressed rotary tidal currents varying in direction of rotation occurred on the two inshore stations. The flow of the average current indicated a counterclockwise circulation.

These currents may affect the movement of king crabs in the planktonic stage.

TABLE OF CONTENTS

Page
Introduction 9
Methods 10
Tidal currents 10
Average currents 12
Discussion of average currents 13
Effects of currents on the king crab larvae . . . 14
Summary 15
Literature cited 15

INTRODUCTION

The movements and physical characteristics of the water in the king crab fishery of southeastern Bering Sea (Figure 1), were investigated in June, 1957, to determine the tidal and average currents in an effort to assess the possible effects they may have on the king crab, *Paralithodes camtschatica* (Tilesius). This investigation was undertaken as part of the program of the King Crab Investigation of the United States Fish and Wildlife Service. The results contribute primarily to the knowledge of the currents observed in southeastern Bering Sea and also to the determination of the effects of the currents on the king crab in the planktonic stage. Future investigations will attempt to relate the water movement to other stages in the life cycle of the crab.

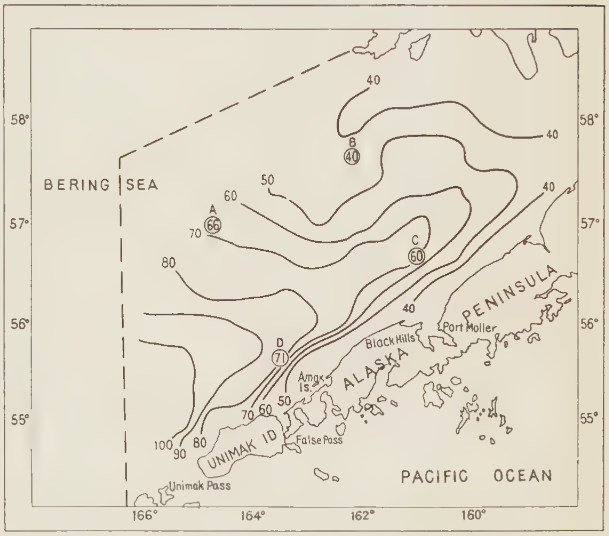


FIGURE 1. Southeastern Bering Sea (within dashed lines) showing current stations and their depths along with the depth contours for the king crab fishery area. Depths given in meters.

The area under investigation is triangular in shape, with an apex in the Bristol Bay region. The land adds freshwater runoff through many streams, among the largest being the Ugashik, Egegik, Naknek, Kvichak and Nushagak Rivers, all of which empty into the Bristol Bay region. The bottom topography is one of gradually increasing depth from Bristol Bay toward the southwest (Figure 1).

The positions of the four current stations are shown in Figure 1. The maximum depths at the sampling stations A, B, C and D are 66, 40, 60 and 71 meters, respectively.

Previous current studies covering part of the same area (surrounding and between stations C and D) were made by scientific personnel aboard the Japanese king crab mothership, *Tokei-maru*, during the crabbing seasons of 1955 and 1956 (International North Pacific Fisheries Commission, 1957). The 1955 data show that the tidal current flowed west-southwest during the ebb-tide hours and east-northeast during the

---

Received for publication August 18, 1959. Original, English.
Source: Contribution from the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, SSR–F 293. INPFC Document No. 281–Rev. 1
Bulletin 5, Int. North Pac. Fish. Comm., August, 1961.

flood-tide hours. In 1956, this general pattern sometimes became obscure. The recorded tidal current velocities did not exceed 1.5 knots in either year.

Past studies contributing to the knowledge of water circulation in and around southeastern Bering Sea include those by the U.S. Coast Guard (1936), Thompson and Van Cleve (1936), and the several mapping, tide, and current surveys made by the U.S. Coast and Geodetic Survey for the Tide and Current Tables for the Pacific Coast of North America.

Dr. Richard H. Fleming and Dr. Maurice Rattray of the Department of Oceanography, University of Washington, generously helped plan the study. Thomas S. Austin, James W. McGary, and Gunter R. Seckel of the U. S. Fish and Wildlife Service, Pacific Oceanic Fishery Investigations, also reviewed the manuscript and made many useful suggestions.

METHODS

From an anchored vessel, the currents were observed at three meters, the top and bottom of the thermocline (where present), and near the bottom, every hour for 38 hours at each of four positions (anchor stations). An Ekman current meter (Ekman, 1932), recording both current velocity and direction, was used for the observations. No correction for the roll of the ship was attempted because during the observations, except at station B, the roll was usually nonexistent.

Before the beginning of the observation period at each station, a bathythermograph (BT) trace was taken to determine the thermocline depth, thereby locating the sampling depths between the surface and the bottom observed depth. (Because of isothermal conditions on station B, only three depths were observed.) The mid-depths thus found were then used throughout the sampling period, regardless of possible later changes in the thermocline depth.

In the analyses of the data for the currents involved, portions of the methods described in both the Manual of Current Observations (U.S. Coast and Geodetic Survey, 1950) and the Admiralty Manual of Tides (Doodson and Warburg, 1941) were used. Tables from the Manual of Current Observations were used to resolve the observed hourly velocities for each station into their respective north and east component velocities which include both the tidal and nontidal currents. (Negative north or east values for the components indicate a current flowing south or west, respectively.) After the component velocities were obtained, the method for obtaining mean sea level by use of multipliers was used (Doodson and Warburg, 1941, p. 111, Table 13.6) to extract the average current from the hourly components. This method has the advantage of reducing casual error which would probably be found in the hourly observations. By then subtracting the north and east components of the average current from the corresponding components of the observed current for each hourly observation, the north and east components of the tidal currents were obtained.

TIDAL CURRENTS

Observations of tidal currents occurring in southeastern Bering Sea show that both rotary and reversing movements occur, the rotary on the more offshore stations (A and B), the usual locus for this type of tidal current; and the reversing on the inshore stations (C and D). The rotation period for all stations was semi-diurnal, accompanied by cyclic variations of the current velocity, also semi-diurnal, thus showing the relationship between the currents and the tidal cycle. Figures 2 through 5 are hodographs of the tidal currents, these showing the hourly observed velocity and direction, the change in current direction between observations and the characteristic rotation occurring on each station.

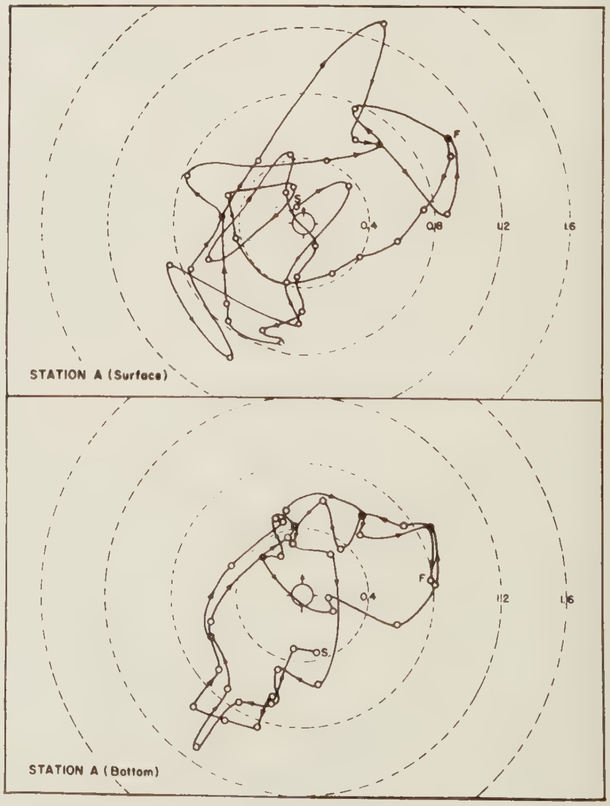


Figure 2. Station A hodograph of surface and bottom tidal currents.

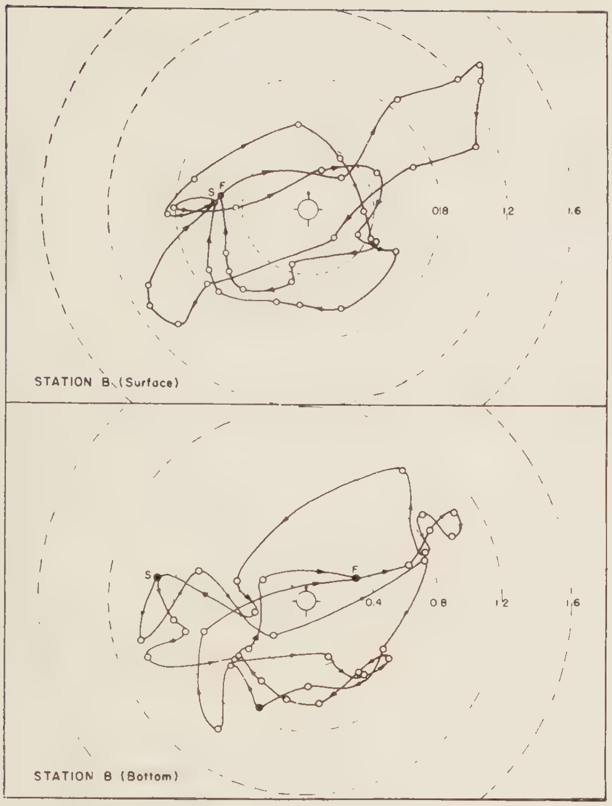


FIGURE 3. Station B hodograph of surface and bottom tidal currents.

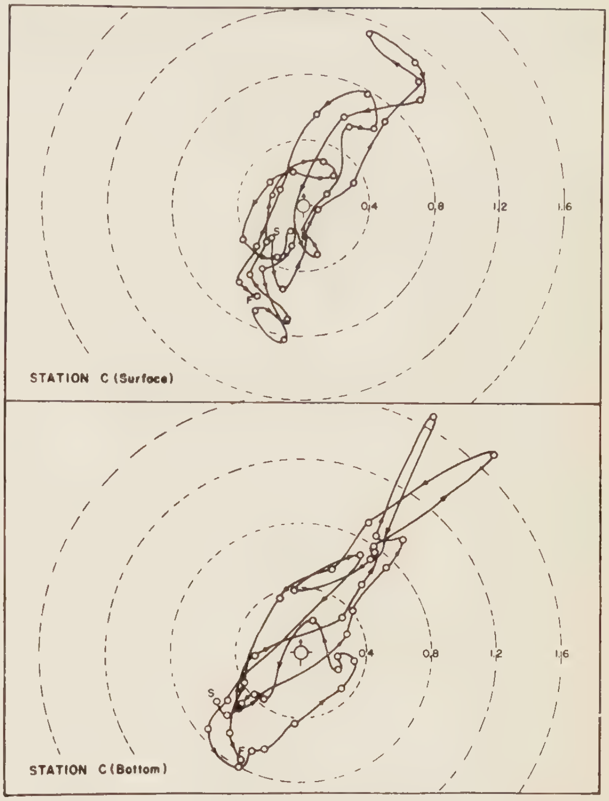


FIGURE 4. Station C hodograph of surface and bottom tidal currents.

In the northern hemisphere, the normal rotation of a rotary current is dextral, unless some other interfering force modifies the rotation. On station A, the rotation was normal at all observation depths; but on B, the direction of rotation varied with depth. Dextral deviation occurred at the surface, while at 20 meters and 40 meters the pattern was confused, both dextral and sinistral rotation occurring at each depth. This pattern is shown in Figure 3.

To determine the principal flood and ebb directions of the rotary currents, the average maximum flood and ebb currents were used, these showing, with slight individual station variation, that the flood and ebb were generally in a northeast-southwest direction at all observation depths. The directions of the flood or ebb and their variations in average velocity and direction with increased depth are shown in Table 1.

On stations C and D, the tidal currents were essentially reversing but with slight rotation, the amount increasing with depth to the bottom on C but remaining approximately the same at all depths on D. Because of the slight rotation, apparently no slack water occurred, as is associated with the completely reversing type of tidal current movement.

TABLE 1. Mean tidal currents for each depth and for the whole water column.

Station	Obs. Depth (m.)	Ebb		Flood	
		Vel. (kt)	Dir. °T	Vel. (kt)	Dir. °T
A	3	0.59	213	0.62	040
	11	0.65	214	0.72	065
	25	0.68	214	0.70	047
	65	0.67	220	0.51	062
	Mean	*0.65*	*215*	*0.65*	*054*
B	3	0.68	238	0.64	056
	20	0.70	235	0.74	080
	40	0.60	237	0.68	065
	Mean	*0.66*	*237*	*0.69*	*067*
C	3	0.43	196	0.55	026
	13	0.53	207	0.56	031
	18	0.50	211	0.63	032
	60	0.54	219	0.65	037
	Mean	*0.50*	*208*	*0.60*	*032*
D	3	0.42	186	0.38	027
	15	0.46	217	0.36	023
	46	0.41	215	0.42	026
	70	0.40	209	0.35	037
	Mean	*0.42*	*207*	*0.38*	*028*

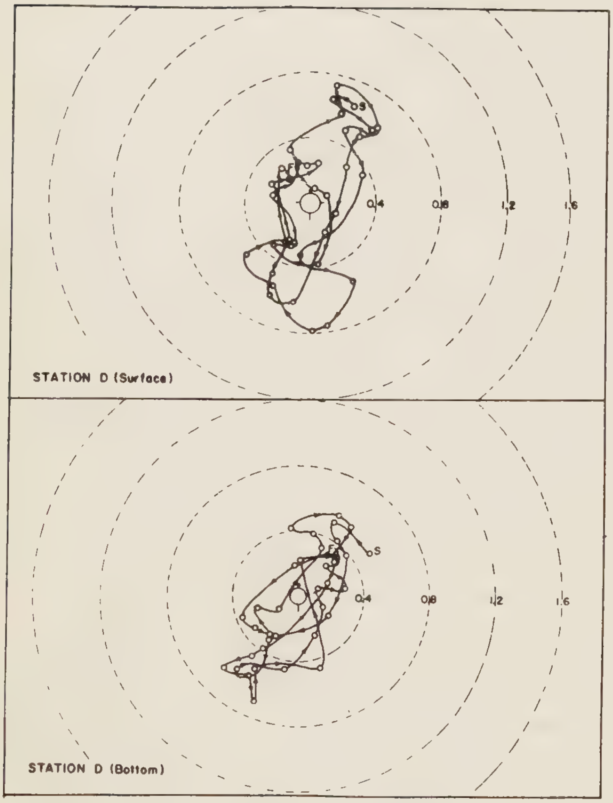


Figure 5. Station D hodograph of surface and bottom tidal currents.

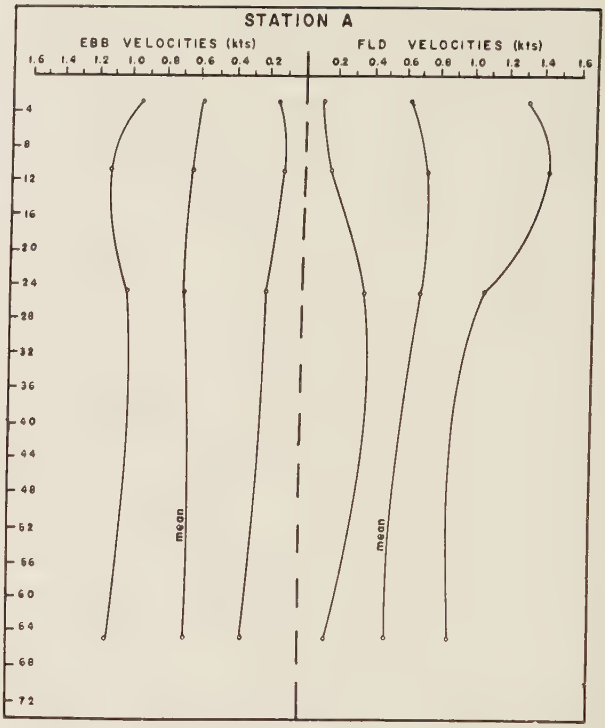


Figure 6. Mean velocity of the flood and ebb tidal currents observed at each depth on station A. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

The sequence of observations on C and D indicated the rotation to be both clockwise and counterclockwise. Above the thermocline on both stations the rotation was counterclockwise, while below the thermocline the rotation vacillated between clockwise and counterclockwise.

The directions of principal flood and ebb were approximately northeast and southwest, respectively. The variations of each with respect to one another and individually with respect to velocity and direction with greater depth are presented in Table 1.

The rotation period of the tidal currents is significant in that it was semi-diurnal at all observed stations and depths, thereby showing relevance to the semi-diurnal tidal cycle. From the hodographs one can see that the time required for one complete revolution was approximately 13 hours.

The velocities of the currents were less regular. Probably because of shallow depths and a smaller cross-sectional area at the inner stations (B and C), the greater velocities occurred on these two stations. The maximum, minimum, and average velocities of the tidal currents (tidal phase considered) and the variation of these with depth for the above stations as well as stations A and D are shown in Figures 6 to 9.

AVERAGE CURRENTS

In the analysis of the original observation data, the average currents were separated from the tidal currents by the method previously described. The results of the analysis indicated a counterclockwise circulation through southeastern Bering Sea (Figure 10). On the inshore stations (C and D), the average current tended to flow into southeastern Bering Sea, the flow being more definite on the inner station (C), at average velocities of 0.09 (C) and 0.05 (D) knots with directions of 072°T and 002°T, respectively. On station D, the average current varied, with depth, between north and east. Because very light winds prevailed during the observations, the probability of the currents being caused by the winds is somewhat decreased. The velocity and flow direction of the average current on stations C and D and their variation with depth are illustrated both in Table 2 and in Figure 10.

Because of strong winds during the observations on

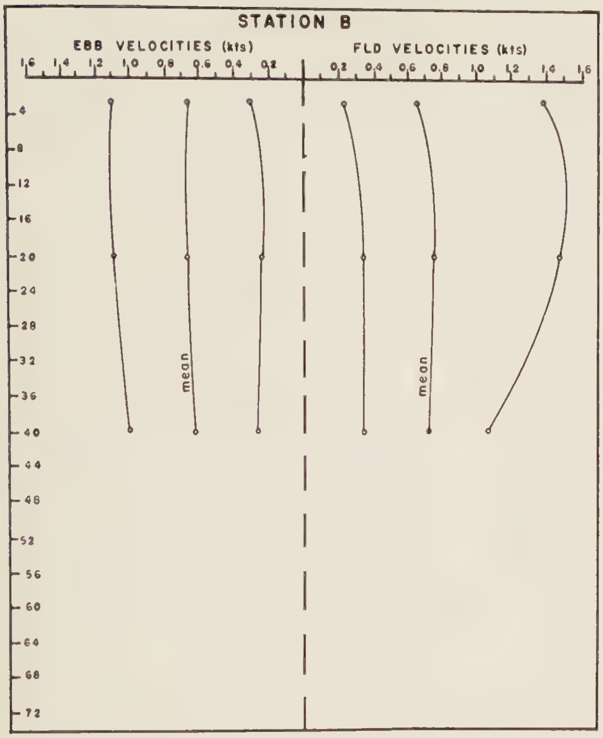


FIGURE 7. Mean velocity of the flood and ebb tidal currents observed at each depth on station B. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

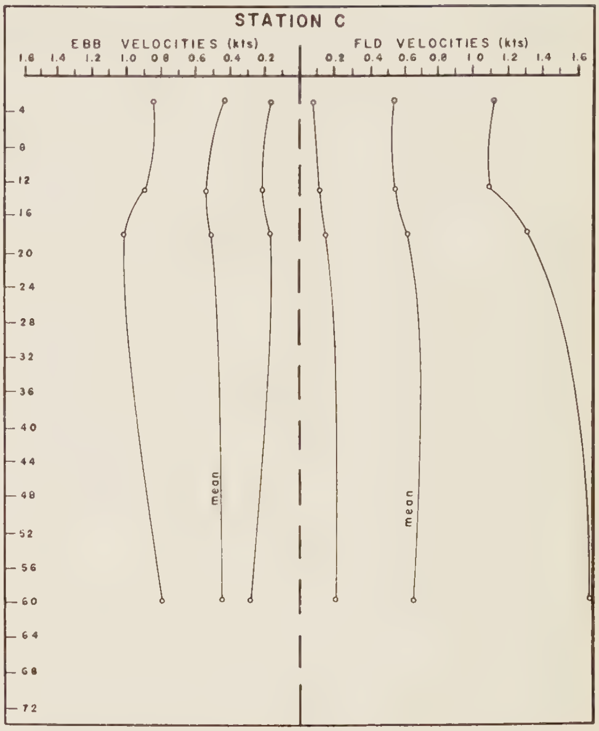


FIGURE 8. Mean velocity of the flood and ebb tidal currents observed at each depth on station C. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

station B, the offshore stations (A and B) had to be considered separately. On station A, the average current flowed essentially southwest at an average velocity of 0.05 knot and an average direction of 223°T. The variations in the current velocity and direction with respect to depth for stations A and B are also shown in Table 2.

On station B, where the wind tended to set up the average current, the wind current was effective throughout the water column. The average current flow was generally between east and southeast: the flow at the surface, 153°T; at 20 meters, 146°T; and at the bottom (40 meters), 112°T. The whole column considered, the mean flow direction of the average current was 137°T at a velocity of 0.11 knot.

To determine whether this station (B) was consistent with the counterclockwise circulation in southeastern Bering Sea, an attempt was made to remove the wind effects in order to determine the average current less the wind current. The wind current velocity was considered to be 2 per cent of the wind velocity and flowing 42° to the right of the wind (Rossby and Montgomery, 1935). Subtracting the vectors of the wind current from the observed average current results in an average current (only the surface considered) following 224°T at 0.14 knot; thus the water movement at this station is probably also consistent with the suspected counterclockwise circulation throughout southeastern Bering Sea.

DISCUSSION OF AVERAGE CURRENTS

Analysis of the data for the average currents on the stations indicated that the water movement through southeastern Bering Sea during the course of these observations was in a counterclockwise direction, that is, toward Bristol Bay along the Peninsula and away from Bristol Bay in the more northern parts of southeastern Bering Sea.

Two investigations in the vicinity of southeastern Bering Sea support the counterclockwise circulation, indicating that this type of circulation may be a continual movement throughout much of the year. Although not in southeastern Bering Sea as defined in Figure 1, the U.S. Coast Guard (1936) has shown a current flowing toward the northwest near Nunivak Island. The subsequent recovery in southeastern Bering Sea of drift bottles released south of Unimak Island (Thompson and Van Cleve, 1936) also lends

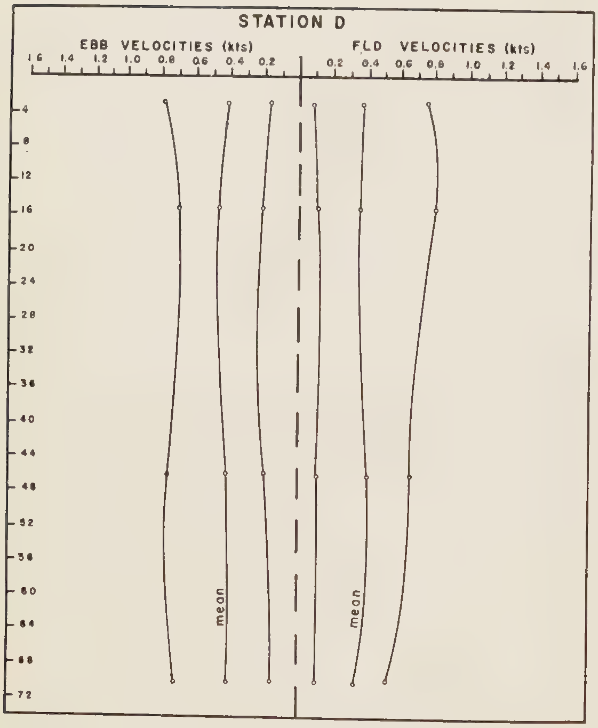


FIGURE 9. Mean velocity of the flood and ebb tidal currents observed at each depth on station D. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

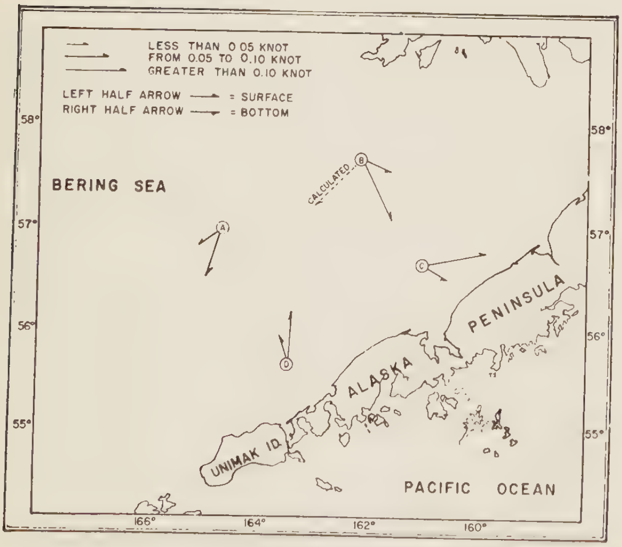


FIGURE 10. Average current vectors for surface and bottom observations. The station B calculated vector is the average current after removal of the wind driven current.

support to the counterclockwise circulation.

The forces fundamental to the above circulation have not been determined because of the lack of sufficient data. The possible forces which may support or contribute to the support of this circulation are (1) the addition of fresh water from streams of the surrounding land, (2) the buildup by winds of a hydraulic head of water along the coasts which upon relaxation would set up temporary currents, and (3) the addition of water to the region from the North Pacific through Unimak Pass as indicated by the before-mentioned drift bottle releases and subsequent recoveries.

TABLE 2. Average current velocity and direction (station B numbers in parentheses are calculated).

Station	Obs. Depth (m.)	Velocity (kt)	Direction °T
A	3	0.08	200
	11	0.03	218
	25	0.07	236
	65	0.02	236
	Mean	*0.05*	*223*
B	3	0.25 (0.14)	153 (224)
	20	0.02	146
	40	0.04	112
	Mean	*0.11*	*137*
C	3	0.11	078
	13	0.11	046
	18	0.11	046
	60	0.04	119
	Mean	*0.09*	*072*
D	3	0.05	003
	15	0.05	326
	46	0.06	056
	70	0.03	344
	Mean	*0.05*	*002*

EFFECTS OF CURRENTS ON THE KING CRAB LARVAE

One of the major effects of the currents would be upon the larvae during the zoea stages of the king crab, when the larvae are planktonic. If we assume that the findings of Marukawa (1933) are valid concerning king crab in the natural environment, the organisms spend approximately 60 days as zoea larvae, of which 5 days are spent in the upper water layers before the larvae migrate to the water layers immediately above the bottom, where the remainder of the time as zoea larvae is spent. The glaucothoeal larvae, formed from the zoea larvae, exist approximately 20 days, this period being spent resting on the bottom or swimming in the water immediately above the bottom.

The effect of the currents on the larvae is greatest in the dispersion or concentration of the larvae, depending upon the type of current flow in their immediate environment. Should hatching occur in a region of linear currents, the zoea would be carried and dispersed by the forth and back movement of the tidal currents, with a net movement of the larvae in the direction of the steady currents. In addition, the larvae would tend to be concentrated where gyrals and eddies are formed.

Because the adult female molts very shortly after the eggs which she has been carrying hatch, we can consider the areas of molting adult females as the areas of larval hatching. In 1957, just prior to the current station observations, both molting females and females with eggs approaching the hatch were observed along the Alaska Peninsula between Amak Island and Port Moller (Figure 1), with the largest abundance near Amak Island. Because of the limited scope of the investigations of crab distribution prior to the current station observations, no other areas of molting females or females with eggs ready to hatch were located.

If we consider the relation between the average velocity of the average current along the Peninsula, 0.04 knot, and the 60-day period the king crab spends as a zoea larvae, we may estimate that the current would carry the larvae approximately 60 miles; variations that might occur would be caused by the tidal currents. In effect, the zoea larvae hatched in the vicinity of Amak Island would be carried into the vicinity of Port Moller. As a matter of observation, the only area where small crabs were located on the abovementioned cruise is in the vicinity of Black Hill, approximately 50 miles from Amak Island. Should hatching occur in other regions, which is very probable, the zoea larvae would be carried, generally, in the direction of the average current for a distance obviously depending upon the net current velocity and the time spent as planktonic larvae.

Because of the habitat of the glaucothoeal larvae, the movements of the larvae caused by the currents are practically indeterminable. About the only time the larvae of this stage would be affected by the currents would be during their periods of swimming, and then perhaps for only short periods of time.

Not only do the currents affect the distribution of the larvae within an area, but they may carry into an area larvae from king crab populations of other areas. Because of the suspected flow of water from the North Pacific into southeastern Bering Sea, by way of Unimak Pass, recruitment of larvae into the Bering Sea from king crab populations south of the Alaska Peninsula is a possibility. False Pass (Figure 1), a small pass between Unimak Island and the Alaska Peninsula, may also be a source of larval recruitment into southeastern Bering Sea.

SUMMARY

The results of current observations in southeastern Bering Sea have been determined by evaluating the characteristics of the currents at two offshore and two inshore stations. The offshore stations revealed dextrally rotating semi-diurnal tidal currents. The maximum currents of between 1.0 and 1.5 knots were flowing parallel to the coast. The minimum current was 0.1 knot, flowing approximately perpendicular to the coast.

The inshore stations showed tidal currents which were also rotary but greatly compressed from the northwest and southeast, so that the major water movement assumed an oval pattern. Here again the currents were semi-diurnal but they varied in the direction of rotation. Maximum observed currents were oriented parallel to the coast with velocities of 1.7 knots at station C and 0.8 knot at D. Minimum observed currents were approximately 0.1 knot.

The maximum observed tidal current velocities at stations A, B, and D tended to decrease with depth but to increase with depth at station C. The minimal tidal currents tended to remain the same or increase in velocity from the surface to the bottom on all stations.

The average current flowed toward Bristol Bay at the inshore stations and seaward at the offshore stations, thus setting up a counterclockwise circulation through southeastern Bering Sea. At all stations, the velocities of the average current tended to decrease with increased depth. Further investigation of the dynamics of southeastern Bering Sea is required in order to determine exactly the forces which set up and maintain the average currents of the area. The permanence of these average currents is of interest because of their importance in the distribution of the king crab larvae during the spring and summer months.

LITERATURE CITED

Doodson, A.T., and H.D. Warburg. 1941. Admiralty manual of tides. *His Majesty's Stationery Office*, London. (Reprinted 1946). 270 pp.

Ekman, V. Walfrid. 1932. An improved type of current meter. *Journal du Conseil*, *7* (1): 1–10.

International North Pacific Fisheries Commission. 1957. Annual report for the year 1956. *International North Pacific*

Fisheries Commission, Vancouver, Canada. 88 pp.

Marukawa, H. 1933. Biological and fishery research on Japanese king crab *Paralithodes camtschatica* (Tilesius). *Journal of the Imperial Fisheries Experimental Station* (Tokyo), *4* (Paper 37). 152 pp.

Rossby, C. G., and R. B. Montgomery. 1935. The layer of frictional influence in wind and ocean currents. *Papers in Physical Oceanography, 3*(3). 101 pp.

Thompson, William F., and Richard Van Cleve. 1936. Life history of the Pacific halibut. (2) Distribution and early life history. *Rept. Inter. Fish. Comm., 9.* 184 pp.

United States Coast and Geodetic Survey. 1950. Manual of current observations. *U.S. Coast and Geodetic Survey, Spec. Publ.* No. 215, Revised (1950) edition. 87 pp.

United States Coast Guard. 1936. Report of oceanographic cruise United States Coast Guard Cutter *Chelan,* Bering Sea and Bering Strait 1934 and other related data. Mimeographed Report. 72 pp.

TUNA SEINES: HOW DEEP?

by Frank J. Hester

• How deep does your tuna seine go?

This question has been partly answered by scientists at the U. S. Bureau of Commercial Fisheries Biological Laboratory, San Diego, as part of the Bureau's program to help the American tuna fishermen increase their catching efficiency. Knowledge of the depth reached by present tuna seines may suggest to the fishermen improvements in design and operation that will minimize the tuna's chances of escaping under the leadline.

The operation of a seine in deep water leaves an avenue of escape for the fish—down. It has been suggested that the depth and nature of the thermocline, the zone of transition from the warmer surface water to the cooler water of the depths, might determine whether or not a set is successful. In other words, the fish would not enter the cold water and would be trapped if the net goes deep enough to reach into or below the thermocline.

In order to find out exactly how deep a tuna seine goes and to test the hypothesis about tuna response to the thermocline, instruments were developed by the writer that can be attached to the net and which will record changes in depth with the passage of time.

These instruments are less than 12" long and cost in the neighborhood of $120, permitting several to be used on the net simultaneously. They are attached to the leadline and ride it overboard as the net is set. The device starts recording upon entering the water. During a recent trip on the tuna seiner *West Point,* 19 days of which were chartered by the Bureau (PACIFIC FISHERMAN, ~~Oct.~~ Nov 1961), several of these devices were attached at various places along the leadline. This particular net measured 435 fathoms in length by 43 fathoms in depth.

Typical results are shown in the three panels of Figure 1. The depth in feet reached by the instruments is indicated down the left-hand scale. The time taken for the instrument to reach the corresponding depth is given in minutes along the bottom scale. Time starts as the instrument enters the water.

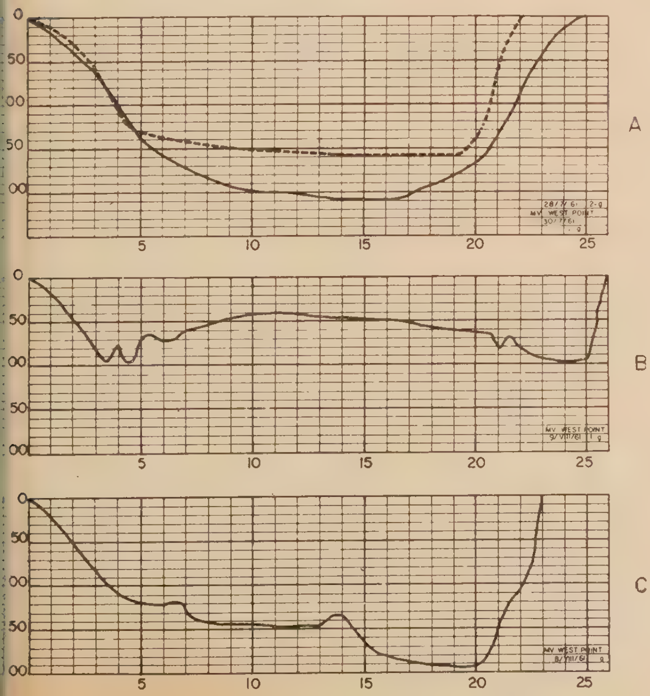
In Panel A, the instrument was located near half-net. Two traces are shown. They represent two different sets made under quite different circumstances and show the variation in depth caused by wind and current acting on the boat and net. The broken line indicates the depth reached by the leadline on a day when the wind and current were tending to drive the boat and net apart. The net reached a depth of 160′ (26½ fathoms). The solid line is from a set made two days later when *West Point* drifted into the net allowing the leadline to sink some 50′ deeper to a depth of 210′ (35 fathoms).

In Panel B, the instrument was attached between the second and third rings from the bunt end. The hump in the trace at 4 minutes occurred when the skiff came alongside and applied power as the end of the net was being passed over from the skiff to *West Point.*

In Panel C, the instrument was fastened to the leadline 5 rings from the hauling end. The gradual sinking as the net is pursed is shown.

The relatively long sinking time of the net is of particular interest, emphasizing the necessity of a good "lead" when the fish are moving. For example, assume that a school of fish is moving at 3 knots, or about 100 yards per minute. Assume also that a bathythermograph trace has been taken showing the thermocline to be well developed at 125′.

From this information, it is possible to calculate the amount of "lead" necessary to allow the leadline to reach the thermocline before the fish reach the net. On an average it takes 1½ minutes to set half the net. From Figure 1-A, one finds that the leadline at the center part of the net takes about 4½ minutes to reach a depth of 125′. The sum of these two times gives a required lead of 6 minutes, during which the fish will travel over a quarter of a mile. This simple cal-



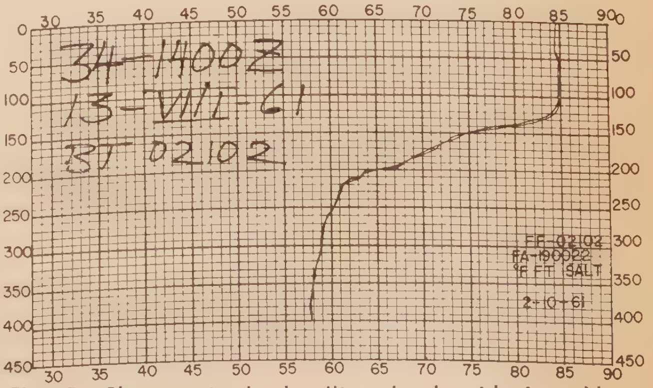


Fig. 1: Changes in the leadline depth with time. Numbers down the lefthand side give depth in feet. Numbers across give time in minutes after the leadline enters the water. A—measurements made at half-net on two different days (see text). B—measurement made two rings in from bunt end. C—measurement made five rings from hauling end—.

Fig. 2: Facsimile of a bathythermograph slide taken on August 13, 1961, aboard **West Point.** Numbers down give depth of feet. Numbers across give sea-water temperature in degrees Fahrenheit.

Mr. Hester is from the US Bureau of Commercial Fisheries, Biological Laboratory, San Diego.

culation does not take into account the distance through the water that the fish can see the net. In clear water, the lead would probably have to be increased.

Decreasing the sinking time of the net is desirable. The most obvious method is to add more weight to the leadline. If a substantial increase in weight is not possible, it may be that the size of the chain used on the bunt end can be decreased and larger chains used from half-net on. This would allow the portion of the net entering the water last to sink faster. On *West Point*, it was found that towing with the skiff while the net was being laid out caused the bunt end to sink more slowly. A similar effect may result if the tension on the purse line is not kept to a minimum during the set.

A reduction in the drag of the webbing will allow the net to sink faster. This can be accomplished by using the largest mesh size and the smallest diameter seine twine possible on each part of the net. The new knotless webbing may also prove effective in reducing drag. The Bureau plans further investigation along these lines.

On twelve separate occasions during the trip on *West Point*, fish were observed to go under the net. Ten of these escapes took place before the net had time to reach the thermocline. Only twice was it likely that the fish actually entered layers of water considerably colder than at the surface.

Figure 2 is a facsimile of a bathythermograph slide taken aboard *West Point* on August 13. The bathythermograph is an instrument that records water temperature and depth on a smoked glass slide as it is lowered on a wire. The trace in Figure 2 starts at a surface temperature of 84.6° F. and ends at 400′ at a temperature of 57.8° F. The thermocline is rather sharp with a temperature change of 20° F. between 100 and 200′.

On this day, *West Point* made on set on a breezing school of Skipjac and tuna which could be seen in th center of the net for 14 minutes afte the skiff was let go. The schools the went down and reappeared outsid the far side of the net. Evidently th fish had gone under the deepest par of the net, which, according to Figur 1-A, should have been at a minimur depth of 150′ well within the thermo cline.

The preceding shows that tuna wil at least under certain circumstance enter the thermocline. The Tuna Be havior Program of the Bureau's Sa Diego Laboratory hopes to be abl to explain in the near future wha these circumstances are. At the sam time, it is possible that the use of th bathythermograph and other instru ments aboard seiners might produc an increase in the percentage o successful sets.

Reprinted from PACIFIC FISHERMAN, *November 1961*

47

REPRINT FROM

CALIFORNIA FISH AND GAME

VOLUME 47 OCTOBER, 1961 NUMBER 4

A METHOD OF PREDICTING TUNA CATCH BY USING COASTAL SEA-SURFACE TEMPERATURES

FRANK J. HESTER
U.S. Bureau of Commercial Fisheries Biological Laboratory,
San Diego, California

Published Quarterly by the
CALIFORNIA DEPARTMENT OF FISH AND GAME
SACRAMENTO

EDMUND G. BROWN, Governor

FISH AND GAME COMMISSION

JAMIE H. SMITH, President .... Los Angeles
HENRY CLINESCHMIDT, Vice President .... Redding
THOMAS H. RICHARDS, JR., Commissioner .... Sacramento
WM. P. ELSER, Commissioner .... San Diego
DANTE J. NOMELLINI, Commissioner .... Stockton

DEPARTMENT OF FISH AND GAME

WALTER T. SHANNON, Director .... Sacramento

OFFICE—FISH AND GAME COMMISSION

722 Capitol Avenue
Sacramento 14

OFFICES—DEPARTMENT OF FISH AND GAME

722 Capitol Avenue
Sacramento 14

1001 Jedsmith Drive
Sacramento

1234 East Shaw Avenue
Fresno

627 Cypress Street
Redding

Ferry Building
San Francisco

724 South Spring Street
Los Angeles

511 Tuna Street
Terminal Island

407 West Line Street
Bishop

271 Tyler Street
Monterey

619 Second Street
Eureka

Room 12, North Ramp
Broadway Pier Building
San Diego

CALIFORNIA FISH AND GAME

Editorial Staff

CAROL M. FERREL, Editor-in-Chief .... Sacramento
JOHN E. FITCH, Editor for Marine Resources .... Terminal Island
ELTON D. BAILEY, Editor for Inland Fisheries .... Sacramento
MERTON N. ROSEN, Editor for Game .... Sacramento
DONALD H. FRY, JR., Editor for Salmon and Steelhead .... Sacramento

A METHOD OF PREDICTING TUNA CATCH BY USING COASTAL SEA-SURFACE TEMPERATURES[1]

FRANK J. HESTER
U.S. Bureau of Commercial Fisheries Biological Laboratory,
San Diego, California

INTRODUCTION

From its start nearly 60 years ago the California tuna fishery has grown into the state's largest fishery, both in value and in pounds landed (Power, 1960). Yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) now are the two most important species and comprise the bulk of the California tuna landings. These are tropical tunas and seldom enter California waters in commercial quantities, the greatest portion of the catch being made by large bait boats and purse seiners operating off Mexico, Central America and South America.

In contrast to the distant fishery supported by yellowfin and skipjack is the fishery for the temperate tunas, albacore (*Thunnus germo*) and bluefin (*Thunnus saliens*). During the summer and fall, both of these species occur off the California and Baja California coasts where they are taken by many boats incapable of making the long trips to the tropics. Baitfishing and trolling produce the major portion of the albacore catch, whereas the bluefin is almost exclusively a purse-seine fishery. For detailed accounts of these methods see Godsil (1938) and Shimada and Schaefer (1956) on baitfishing, Scofield (1956) on trolling, and Whitehead (1931), Scofield (1951) and Orange and Broadhead (1959) on purse seining.

The catches from the California albacore and bluefin fisheries have varied markedly from year to year. The author, and other researchers, feel that some of this variation has been attributable to changes in the ocean climate off the California coast. The present study attempts to relate fluctuations in the temperate tuna catch (bluefin and albacore) to environmental conditions as measured by sea-surface temperatures at two shore stations in southern California.

ERRORS IN ESTIMATING AVAILABILITY FROM CATCH RECORDS

The majority of the local tuna catch has been made during the summer months. The seasonal nature of the California tuna fishery indicates that fluctuations in catch due to changes in the geographical distribution of the fish are of major importance. Some of this variation may be due to changes in the behavior of the fish rather than their actual absence from California waters. Present knowledge makes it difficult, if not impossible, to distinguish between fluctuations caused by absence and those caused by behavioral differences. For this study, no attempt is made to separate these two causes. Instead it is assumed that two populations of tuna, one of albacore and one of bluefin, are so located that during the summer months their ranges include the waters off southern California. The degree of presence (availability) of these populations is sampled by their respective fisheries. This method of sampling is subject to errors introduced by inclement weather and changes in the economy. Both of these errors can be treated as part of the sampling error. Variations in landings due to changes in population size (abundance) can also be treated as a randomly distributed sampling error.

---

[1] Submitted for publication March, 1961.

An additional source of variation in the landings may be attributed to changes in the size of the fishing fleet. The error from this source can not be randomly distributed for the number of boats in both the albacore and the bluefin fleets has declined since the 1940's, but variations due to changes in fleet size are assumed to be small.

DISTRIBUTION OF CATCH

According to Clemens (1955), the usual albacore season starts around the middle of June. During the three years covered in his report, 1951-1953, the first catches were made in the vicinity of Cedros and Guadalupe Islands. As the summer progressed, the fishery moved up the coast terminating in the fall with the majority of the catches being made north of Point Conception.

During the spring of 1960, the Bureau of Commercial Fisheries, San Diego Biological Laboratory, in cooperation with the U. S. Navy, initiated an offshore albacore survey. Trolling gear was placed aboard five radar picket vessels stationed about 250 miles offshore from southern California to Washington. The early season catch as reported by these ships seemed to follow the northward and inshore march of the 59 degree isotherm (Johnson, 1960). Apparently the northward movement of the fishery reported by Clemens is related to sea temperature. This concept was originally developed by Thompson (1917), who utilized mean minimum air temperature data from maritime stations as an index of sea temperature. He observed a striking correlation between observed temperatures and the northward movement of the fishery. Recently, Radovich (1961) has pointed out that movement of the fishery is related to temperature.

It is common knowledge that the bluefin fishery develops further south than the albacore fishery, often starting in June near Cape San Lazaro, Baja California, and shows a similar northward movement later in the season. Catches are made off southern California in the late summer and early fall (Skogsberg, 1925). Schools are reported north of Point Conception, but the catch from this area is negligible.

That temperature does play an important role in the movements of these fishes was dramatically shown by changes in the catch localities for albacore and bluefin during the recent warm period 1957 to 1960. Sea-surface temperatures during these years ranged 4 degrees F. higher than the 10-year mean (McGary, 1960). The usually large fishery for albacore off Baja California failed; it developed instead several hundred miles to the north. At the same time, the bluefin catch off southern California increased, resulting in the largest landings from California waters since the late 1940's. The striking contrast between the most productive bluefin areas in August 1952 and 1953, two years of cold water temperatures, and August 1957 and 1958, is shown in Figure 1. The data came from tuna seiner logbooks maintained by the fleet since 1952 for the Inter-American Tropical Tuna Commission.

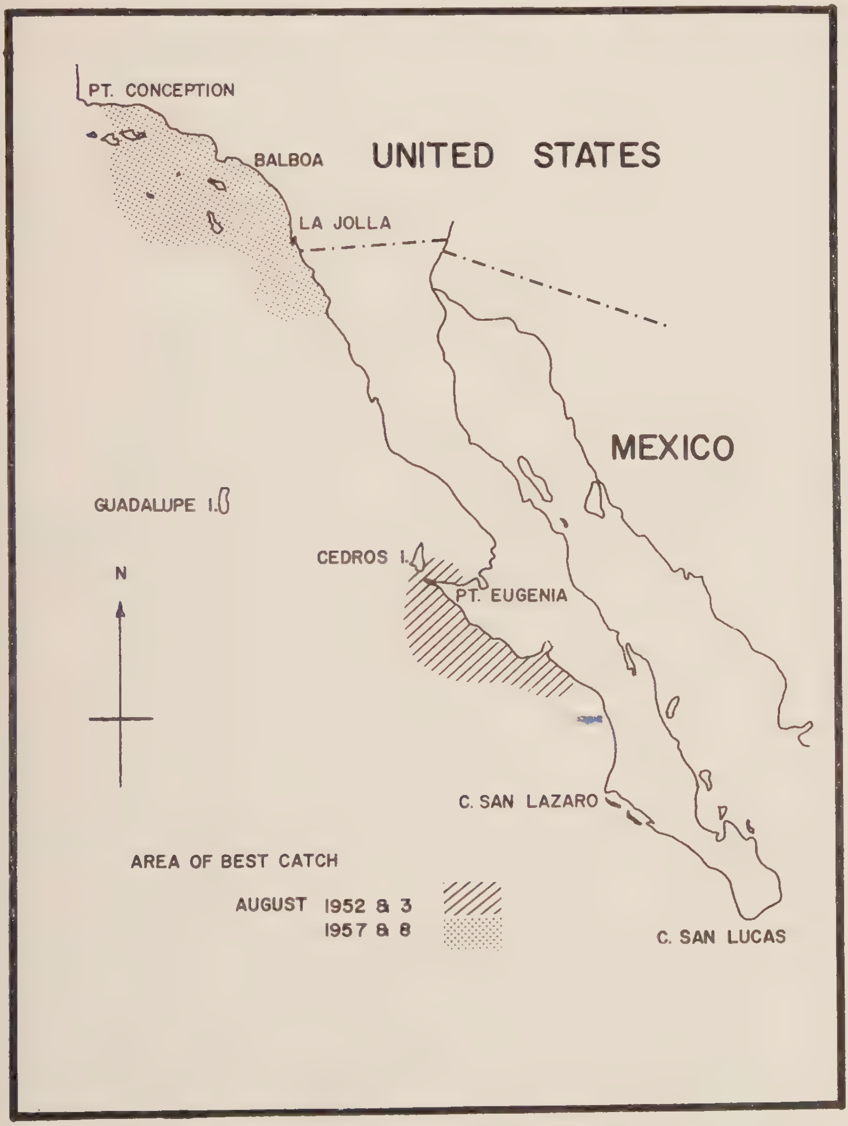

PT. CONCEPTION
BALBOA
UNITED STATES
LA JOLLA
MEXICO
GUADALUPE I.
CEDROS I.
N
PT. EUGENIA
C. SAN LAZARO
AREA OF BEST CATCH
AUGUST 1952 & 3
1957 & 8
C. SAN LUCAS

FIGURE 1. Changes in the most productive areas for bluefin fishing between August 1952 and 1953 and August 1957 and 1958.

TEMPERATURE EFFECTS

Any attempt to postulate some particular optimum temperature for albacore would have to explain the difference of several degrees in water temperature existing between our troll fishery and the Japanese pole and line fishery. The best Japanese catches occur in waters warmer than off California (Calif. Mar. Res. Comm., 1960, Murphy). The reverse seems to be true for bluefin, as the Japanese net fishery is conducted at a lower temperature than ours (Uda, 1957). In this case, however, a different population of bluefin tuna may be involved since trans-Pacific migrations have not been demonstrated for bluefin as they have for albacore (Otsu, 1960).

It is possible that temperature affects the behavior of a fish in such a way that the best catches for particular types of gear occur at different temperatures. For example, there is some indication that bait-fishing for albacore is more successful later in the season when the schools are more concentrated. This concentration of schools may be related to the higher water temperatures which occur later in the season.

Several indirect effects might influence the capture of tunas. One is the increased basic productivity found in areas of upwelling. Schaefer (1957) also points out that areas of tropical tuna concentrations appear to coincide with regions of high basic productivity. An increase in the amount of tuna food in an area could result in a temperature-tuna relationship seemingly dependent upon the cooler water associated with the upwelling.

High productivity as well as other factors which may be correlated with temperature can produce changes in water clarity and these in turn may influence fishing success. Some attempts have been made to relate fishing success to turbidity (Whitehead, *op. cit.* and Murphy, 1959). The latter relates albacore catch to underwater visibility on the assumption that troll caught albacore are sight feeding. Thus trolling success might be poor in the turbid coastal water close to shore, whereas net fishing for bluefin may depend upon poor underwater visibility resulting in better catches near shore and at night.

CHANGES IN LANDINGS

Yearly tuna landings are reported by the California Department of Fish and Game in its *Fish Bulletin* series. The catch is divided into fishing boat landings from waters north of the California state line, California waters, and waters south of the International Border. The total landings from 1945 through 1959 are given in Table 1. The cut-off date, 1945, was chosen in order to exclude some of the economic factors present during the war years. In addition to total landings, albacore and bluefin landings from south of the International Border and from California waters have been provided. An increase in the bluefin catch from California waters was coincident with the warm-water conditions in 1957 and 1958. For comparison, tropical tuna landings from California waters also have been given in Table 1. The presence of commercial quantities of these fish in California waters may be regarded as a further indication of changes in the oceanic

TABLE 1

Landings in Millions of Pounds for Bluefin and Albacore
Thousands of Pounds for Yellowfin and Skipjack [1]

Year	Total California albacore landings*	Total California bluefin landings	Landings from south of the International Border		Landings from California waters			
			Bluefin	Albacore	Albacore	Bluefin	Yellowfin	Skipjack
1945	21.77	20.59	6.45	12.26	8.78	14.14	4.96	93.08
1946	18.06	22.03	6.50	8.96	9.10	15.53	32.65	1,747.06
1947	13.14	20.83	6.07	5.76	7.40	14.76	3.32	893.05
1948	36.42	6.53	4.84	25.93	10.50	1.69	0.41	319.19
1949	44.02	4.39	2.12	23.58	20.40	2.27	9.88	26.68
1950	61.75	2.74	2.73	23.60	38.14	0.01	1.46	12.42
1951	30.68	3.86	3.02	17.62	13.28	0.84	0.00	0.59
1952	49.79	4.58	3.67	26.70	23.10	0.91	0.00	0.53
1953	33.83	9.17	5.87	20.49	13.30	3.90	0.10	1.28
1954	26.11	21.02	15.37	11.82	14.29	5.65	0.00	14.40
1955	29.00	13.61	11.13	19.69	9.31	2.48	0.00	1.24
1956	37.04	12.62	10.01	21.06	15.87	2.61	0.10	0.88
1957	43.47	20.31	9.85	20.91	22.61	10.46	70.85	353.46
1958	27.10	30.72	15.11	0.72	25.39	15.61	417.71	2,488.91
1959	32.74	15.30	2.17	0.00	32.52	13.13	81.68	1,380.96

[1] Source—Calif. Dept. Fish and Game, Marine Resources Operations
* Includes some fishing boat landings from north of the state line.

climate off California. The data were plotted (Figure 2) using fishing boat landings reported from California waters for skipjack, yellowfin, and bluefin, and landings from waters south of the International Border for albacore. The figure indicates that a change took place towards the end of the 1940's which was reversed in 1957. This change was characterized by a decline in skipjack, yellowfin, and bluefin landings, and a rise in albacore. The rise in the albacore catch and the decline in bluefin are most interesting. Since the two fisheries are essentially independent, albacore being caught with hook and line and bluefin being netted, fluctuations due to fishermen's preference for one species over the other are eliminated.

This relationship can be explained by postulating two population centers, one for albacore and one for bluefin. These centers of abundance, which are indicated by the best catches for the two species, do not coincide, bluefin occurring south and inshore of albacore. During cold years, the center of the albacore population would move south resulting in higher catches south of the International Border. Logbook records show that substantial catches of albacore were made off Baja California during the early 1950's when bluefin were rare north of Cedros Island. During warm years, the albacore would move northward resulting in lower catches in the southern fishery. At the same time, the center of the bluefin population also would move northward resulting in increased bluefin catches in California waters. The relationship is examined in more detail in Figure 3 where southern albacore catches and northern bluefin catches have been plotted against each other. A northward movement of bluefin should be accompanied by an increase in bluefin catch and a decrease in albacore catch.

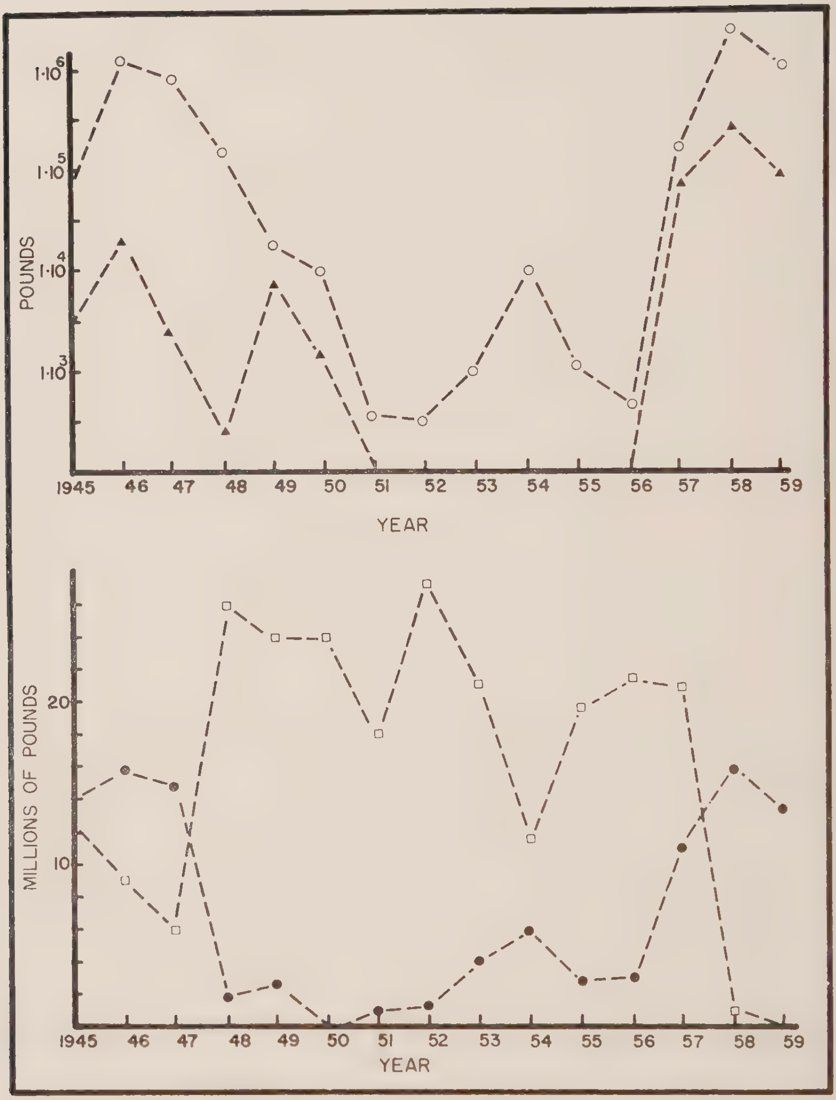


FIGURE 2. Top: *Skipjack*—fishing boat landings from California waters, open circles. *Yellowfin*—fishing boat landings from California waters, closed triangles. Bottom: *Albacore*—fishing boat landings from waters south of the International Border, open squares. *Bluefin*—fishing boat landings from California waters, closed circles.

A high inverse correlation exists between bluefin and albacore catches as is shown by a correlation coefficient of —0.84. This coefficient can be interpreted to mean that 84 percent of the fluctuations in landings between the two species are due to some common element. In this case it is assumed that the common element is movement of the fish populations due to environmental factors.

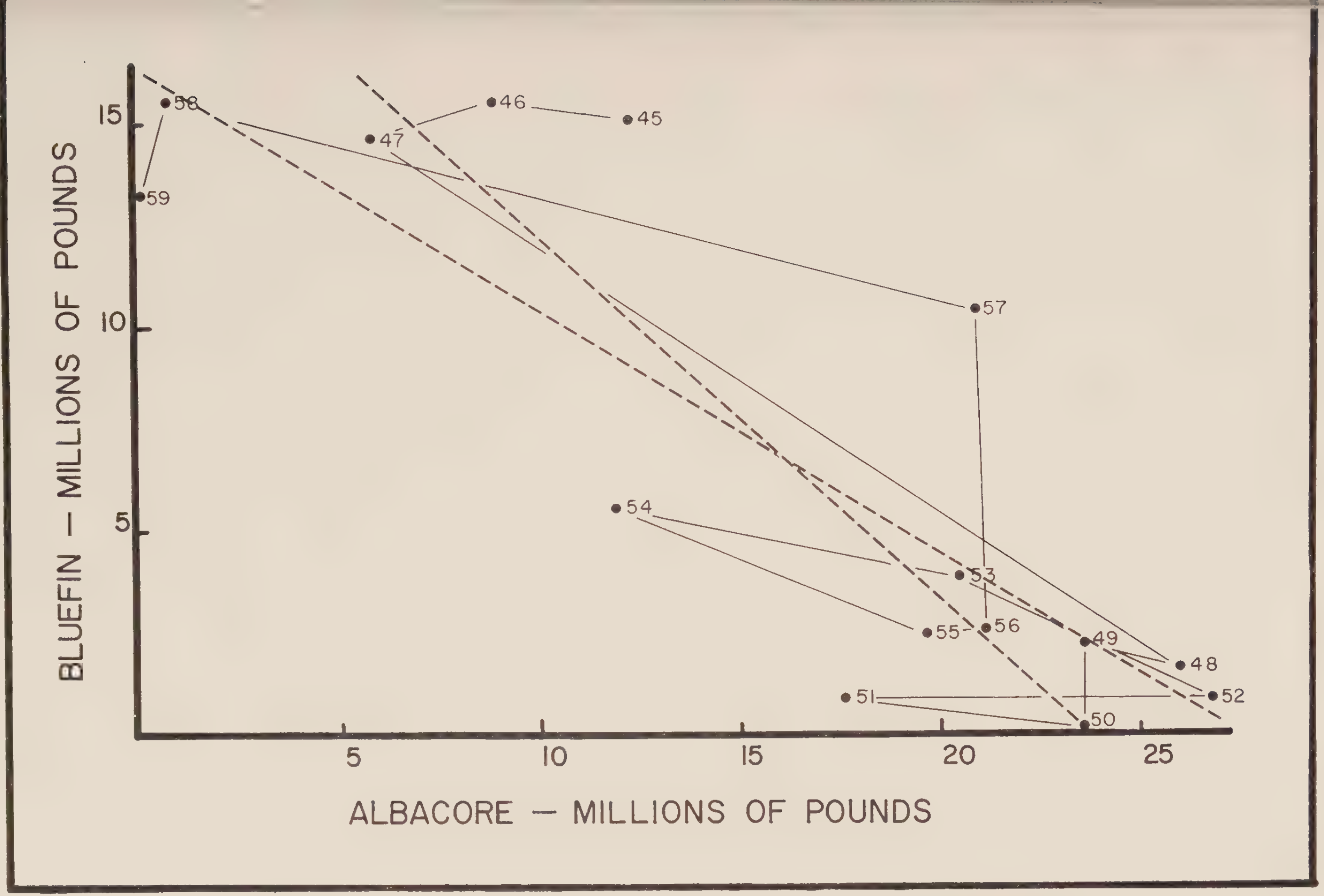


FIGURE 3. *Albacore*—fishing boat landings from south of the International Border. *Bluefin*—fishing boat landings from California waters. Numbers on graph are years 1945 through 1959.

TEMPERATURE AS AN INDEX OF AVAILABILITY OF ALBACORE AND BLUEFIN

A source for sea temperature data covering the same period and areas as the catch is difficult to find. Since 1949, California Cooperative Oceanic Fisheries Investigations (CCOFI) has run a series of station lines from San Francisco to Cape San Lucas but the coverage is missing for certain key months. Sea-surface temperatures collected by the U. S. Weather Bureau are sparse prior to 1950. However, sea-surface temperatures are available from shore stations along the California coast back to 1935. These data have been collected by the University of California, Scripps Institution of Oceanography, under a program initiated by Dr. George F. McEwen. Observations from the two stations south of latitude 34° N., La Jolla, and Balboa Pier, have been averaged for use in this study (Table 2). Although these shore stations are in the northern part of the area to be considered, they probably will provide an index to environmental changes in the sea off southern California and northern Baja California. This is due to the common circulation of the waters from Point Conception to Point Eugenia (Calif. Mar. Res. Comm., 1958).

The bulk of the local tuna has been caught during July, August and September. A comparison has been made in Figure 4 between the annual catch of bluefin from California waters and albacore from waters south of the International Border, and the sea-surface temperatures at Balboa and La Jolla averaged together for these three months. Two lines were fitted by the method of least squares, A-A' for albacore and B-B' for bluefin. The equation for A-A' is:

$$1)\ A_s = 163.84 - 7.65T_s$$

where A_s is the estimated albacore catch (millions of pounds) south of the International Border and T_s is the average surface water temperature (degrees Centigrade) July through September at Balboa and La Jolla. The standard error of an estimated catch is 7.412 and the standard error of the slope is 2.68. The equation for B-B' is:

$$2)\ B_s = -112.32 + 6.17T_s$$

where B_s is the estimated bluefin catch (millions of pounds) from California waters and T_s is as above. The standard error of an estimated catch is 4.607 and the standard error of the slope is 1.66. The slope of the line in equation (1) is significant at the 5 percent level, the slope in equation (2) at the 1 percent level. The inverse relationship between the bluefin and albacore catch is apparent.

A study of year to year temperature changes indicates that warm years along the southern California coast are preceded by warm water temperatures in winter. This has been attributed to increased advection from the south during the winter months (Calif. Mar. Res. Comm., 1953) and other causes. The relationship between winter and summer temperatures provides a convenient way to predict unusually good or bad years for the local tuna fishery. In Figures 5 and 6, the southern albacore and northern bluefin catches were plotted against Balboa and La Jolla sea-surface temperatures averaged together for the months

TABLE 2

Sea-Surface Temperatures, Degrees Centigrade, for the Years 1945 Through 1959 at La Jolla and Balboa

Year	Yearly mean		SUMMER							WINTER								
			Mean-La Jolla			Mean-Balboa			Summer mean	Mean-La Jolla				Mean-Balboa				Winter mean
	La Jolla	Balboa	July	Aug.	Sept.	July	Aug.	Sept.	La Jolla + Balboa	Jan.	Feb.	Mar.	Apr.	Jan.	Feb.	Mar.	Apr.	La Jolla + Balboa
1945	16.61	16.20	20.02	21.39	20.31	18.78	19.77	19.36	19.94	14.17	13.99	13.09	13.82	14.27	14.31	13.34	13.94	13.87
1946	16.83	16.62	20.39	21.21	18.89	20.00	19.69	19.04	19.87	13.03	12.78	13.63	16.17	13.49	13.29	13.53	15.96	13.98
1947	16.88	16.78	19.29	20.01	19.56	19.10	20.30	19.01	19.54	13.45	13.86	14.87	15.76	13.67	14.03	15.05	15.89	14.57
1948	16.08	15.62	18.47	19.86	19.31	17.98	18.15	18.41	18.70	13.56	13.14	13.41	14.80	13.44	12.78	13.30	14.29	13.59
1949	16.52	15.97	20.15	20.86	20.19	18.95	19.24	18.62	19.67	12.28	12.66	13.42	14.40	12.13	12.31	12.96	14.37	13.07
1950	16.40	15.85	20.54	19.11	19.31	18.64	18.16	18.83	19.10	12.76	12.97	13.91	15.67	12.56	12.82	13.81	15.06	13.70
1951	16.62	15.78	20.14	19.69	17.77	18.85	17.84	16.80	18.52	13.25	13.48	13.99	15.99	13.05	13.44	13.33	15.06	13.95
1952	16.28	15.31	18.06	20.90	18.12	16.25	18.32	16.21	17.98	13.71	13.59	13.46	15.42	13.21	13.41	12.94	14.89	13.83
1953	16.24	15.51	20.57	20.69	17.63	19.17	18.60	16.36	18.81	13.97	13.18	13.65	14.60	13.74	13.01	12.86	13.75	13.60
1954	16.86	15.02	21.25	21.26	19.10	17.91	17.27	16.29	18.86	14.10	14.32	14.03	15.06	14.05	14.42	13.84	15.24	14.38
1955	16.48	15.34	19.60	21.48	20.58	18.11	17.62	17.92	19.22	13.38	12.95	14.35	14.14	13.55	12.51	14.29	12.99	13.52
1956	16.37	15.69	19.96	21.08	18.82	18.27	19.69	17.40	19.20	12.61	12.89	13.36	14.77	12.60	12.68	13.37	14.15	13.30
1957	17.36	16.48	20.87	21.55	19.15	19.87	20.75	18.44	20.10	14.81	14.34	14.83	15.29	14.56	14.06	14.83	13.75	14.56
1958	17.84	17.43	19.39	20.49	20.21	18.32	19.54	19.49	19.58	16.06	16.00	15.34	17.06	15.82	15.86	15.32	17.11	16.07
1959	18.35	17.71	21.95	21.27	21 01	20.29	18.90	20.27	20.84	16.00	15.21	16.19	17.02	15.49	15.02	15.96	16.22	15.89

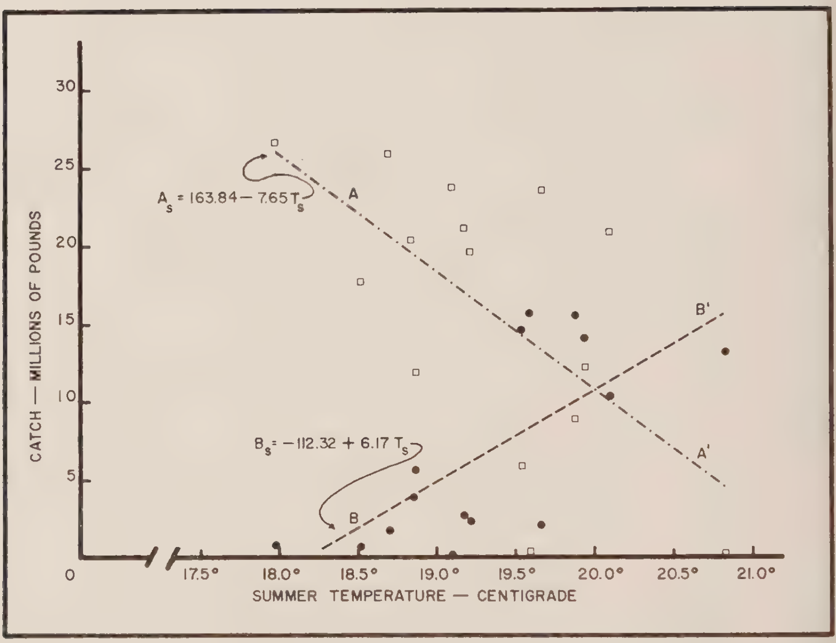


FIGURE 4. *Albacore*—yearly fishing boat landings from waters south of the International Border, open squares. *Bluefin*—yearly fishing boat landings from California waters, solid circles. *Temperature*—average July, August and September sea-surface temperature, Balboa and La Jolla.

January through April for each of the years 1945 through 1959. Lines were fitted to the data and the equations are:

$$3)\ A_w = 135.11 - 8.44T_w$$

where A_w is the estimated albacore catch south of the International Border and T_w is the average winter sea-surface temperature January through April at Balboa and La Jolla. The standard error of an estimated catch is 5.324 and the standard error of the slope is 1.79;

$$4)\ B_w = -61.41 + 4.84T_w$$

where B_w is the estimated bluefin catch from California waters and T_w is as above. The standard error of an estimated catch for bluefin is 4.853 and the standard error of the slope is 1.45. Both slopes are significant at the 1 percent level. Of interest is the reduction in standard error for both species, implying a closer tie between winter conditions and subsequent events than between the simultaneous events, catch and summer water temperature, shown in Figure 4.

The relation does suggest temperature as an easily measured indicator on which to base predictions. The statistical validity of the preceding is based on the assumptions that the temperatures are measured without error, that the variations in catch due to sampling by the fishery are normally distributed about some mean value, and that the standard deviations for the catch at each temperature are equal. The temperature for any year was the average of over 200 observations and errors from this source should be minimal.

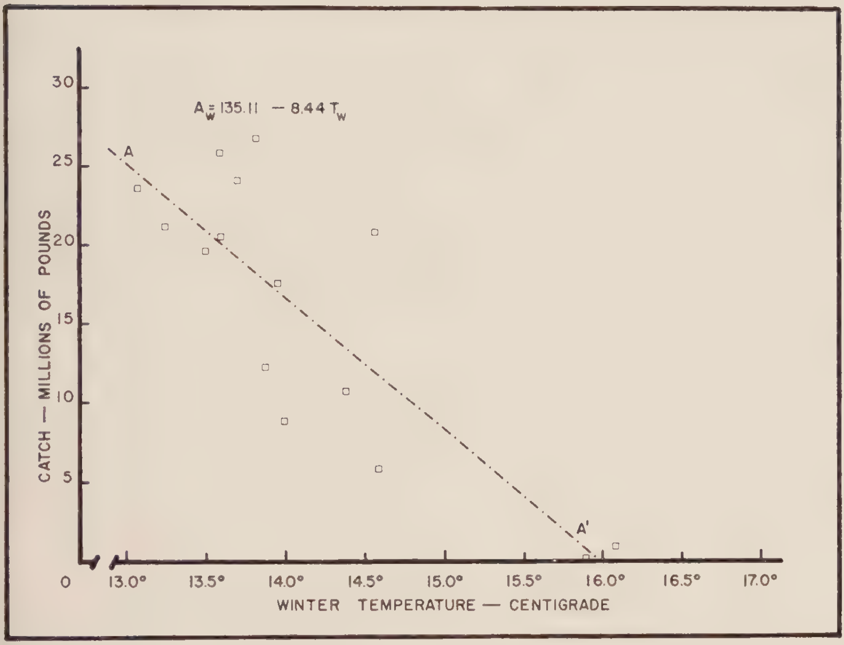


FIGURE 5. *Albacore*—fishing boat landings from waters south of the International Border. *Temperature*—average sea-surface temperature January through April, Balboa and La Jolla.

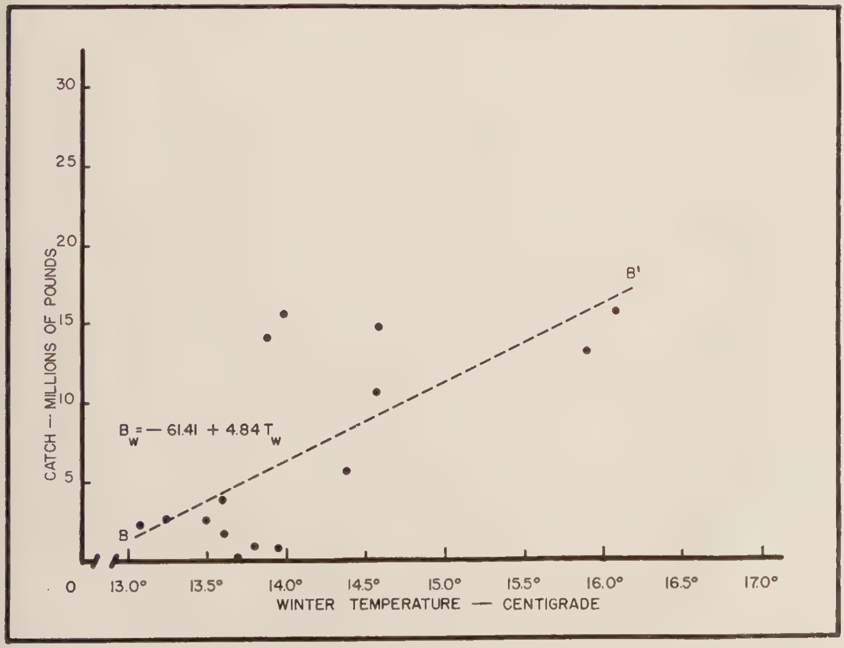


FIGURE 6. *Bluefin*—fishing boat landings from California waters. *Temperature*—average sea-surface temperature January through April, Balboa and La Jolla.

By accepting the preceding assumptions, it now should be possible to make catch predictions based on temperature. For example, the four-month average winter water temperature for Balboa and La Jolla during 1960 was 14.35 degrees C. From equation (4) we would then estimate the 1960 California bluefin catch to be 8.0 million pounds and from (3) we would estimate the albacore catch south of the International Border to be 13.9 million pounds. Fiducial limits at about the 66 percent probability level would be 3.2 to 12.8 million pounds for bluefin. Similarly, we can estimate that the 1960 albacore landings from waters south of the International Border will lie between the 66 percent confidence limits of 8.5 and 19.3 million pounds. The actual landings for 1960 are not yet available from the California Department of Fish and Game, so it is not possible to check our forecast. Preliminary reports, without regard to area of catch, indicate that the bluefin figure should be close. An early season tie-up by the albacore fleet will probably result in an over-estimate for the albacore prediction. However, since the equations were derived from data that were uncorrected for economic factors, the source of error due to the tie-up should be already included in our confidence limits.

FORECASTING TOTAL CATCH

So far only catches from limited areas have been considered. An attempt to predict total California landings from sea-surface temperatures is more involved. Total California albacore landings (Table 1) are made up of fish from south of the International Border, fish from California waters, and fish from north of the California state line. Although temperature might influence the movements of the fish in the latter two areas, the errors, which before could be treated as random sampling errors, become large north of the International Border. This is primarily due to large changes in fleet size depending on the success of the salmon troll fishery and the southern albacore fishery. The effect of weather probably is important too and would produce greater variability in the size of the catch north of Point Conception. For this reason an average of the 15-year landings is probably the best available estimate for the landings from California waters for any year. This average is 17.60 million pounds. Until a pre-season measure of changes in effort is available for the albacore fishery, a closer estimate of total catch cannot be made.

Total bluefin landings closely follow the trend of the landings from California waters. The relationship between total bluefin landings and winter water temperature is given by:

$$5)\ B_t = -76.52 + 6.40T_w$$

where B_t is total bluefin landing in millions of pounds and T_w is the winter sea-surface temperature previously described. The standard error of an estimated catch is 6.947. The standard error of the slope is 2.08. The slope is significant at the 1 percent level. The total estimated California bluefin catch for 1960 is 15.32 ± 6.9 million pounds at the 66 percent confidence level.

SUMMARY

1. Tuna landings from southern California waters fluctuate from year to year both in quantity and area of capture.

2. A correlation has been shown between sea-surface temperature (July, August, and September mean) at two southern California shore stations and bluefin and albacore catch from selected areas.

3. This correlation holds when winter water temperatures are used permitting a forecast of bluefin and albacore catch before the season begins.

4. Equations have been given for predicting any year's bluefin and albacore catch in selected areas and limits of confidence are set.

5. Landings from the selected areas have been compared with total California landings.

REFERENCES

California Marine Research Committee
1953. California cooperative oceanic fisheries investigations, Prog. Rept., 1 July 1952—30 June 1953, 44 pp.
1958. *Ibid.*, Prog. Rept., 1 July 1956—1 Jan. 1958, 57 pp.
1960. *Ibid.*, Rept., 1 Jan. 1958—30 June 1959, vol. 7, 217 pp. (Murphy, p. 168)

Clemens, H. B.
1955. Catch localities for Pacific albacore (*Thunnus germo*) landed in California, 1951 through 1953. Calif. Dept. Fish and Game, Fish Bull. 100, 28 pp.

Godsil, H. C.
1938. The high seas tuna fishery of California. Calif. Div. Fish and Game, Fish Bull. 51, 41 pp.

Johnson, J. H.
1960. Navy vessels troll for albacore. U. S. Bur. Com. Fish., Calif. Fish. Market News Mon. Sum., Pt. 2—Fish. Inform., August 1960, pp. 2-4.

McGary, J. W.
1960. Surface temperature anomalies in the central North Pacific, January 1957-May 1958. Calif. Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., vol. 7, pp. 47-51.

Murphy, G. I.
1959. Effect of water clarity on albacore catches. Limnol. and Oceanog., vol. 4, no. 1, pp. 86-93.

Orange, C. J. and G. C. Broadhead
1959. 1958-1959—A turning point for tuna purse seine fishing? Pac. Fisher., vol. 57, no. 7, pp. 20-27.

Otsu, T.
1960. Albacore migration and growth in the north Pacific Ocean as estimated from tag recoveries. Pac. Sci., vol. 14, no. 3, pp. 257-266.

Power, E. A.
1960. Fishery statistics of the United States 1958. U. S. Bur. Comm. Fish., Stat. Digest 49, 424 pp.

Radovich, J.
1961. Relationships of some marine organisms of the northeast Pacific to water temperatures. Calif. Dept. Fish and Game, Fish Bull. 112, 62 pp.

Schaefer, M. B.
1957. Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1956. Inter-Amer. Trop. Tuna Comm., Ann. Rept. for 1956, pp. 33-70.

Scofield, W. L.
1951. Purse seines and other roundhaul nets in California. Calif. Dept. Fish and Game, Fish Bull. 81, 83 pp.
1956. Trolling gear in California. Calif. Dept. Fish and Game, Fish Bull. 103, 45 pp.

Shimada, B. M. and M. B. Schaefer
1956. A study of changes in fishing effort, abundance and yield for yellowfin and skipjack tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., vol. 1, no. 7, pp. 351-469.

Skogsberg, T.
1925. Preliminary investigation of the purse seine industry of southern California. Calif. Div. Fish and Game, Fish Bull. 9, 95 pp.

Thompson, W. F.
1917. Temperature and the albacore. Calif. Fish and Game, vol. 3, no. 4, pp. 153-159.

Uda, M.
1957. A consideration on the long years trend of the fisheries fluctuation in relation to sea conditions. Japanese Soc. Sci. Fish., Bull., vol. 23, no. 7 and 8, pp. 368-372.

Whitehead, S. S.
1931. Fishing methods for the bluefin tuna (*Thunnus thynnus*) and an analysis of the catches. Calif. Div. Fish and Game, Fish Bull. 33, 32 pp.

o

49105 9-61 300 *printed in* CALIFORNIA STATE PRINTING OFFICE

Reprinted from CHESAPEAKE SCIENCE
Vol. 2, No. 1-2, March-June 1961
Printed in U.S.A.

Appearance of the Gag, *Mycteroperca microlepis*, in Coastal Waters of Virginia[1]

ABSTRACT

Eighteen young gag, *Mycteroperca microlepis*, 61–186 mm F.L., were recorded from Chincoteague Bay, Eastern Shore waters, off Virginia Beach, and within Chesapeake Bay from July to November 1960. Average lengths at progressive collecting periods suggest rapid growth. Coloration and pattern varied somewhat among the specimens.

The gag, *Mycteroperca microlepis* (Goode and Bean), a grouper common to Florida waters with a range extending northward beyond Virginia, has not been commonly reported in Virginia before 1960 except for isolated specimens. One fish was taken at Old Point Comfort (Evermann & Hildebrand, 1910) and three others reported from Virginia, no specific locations (Smith, 1959). During 1960 several small specimens were taken (Table 1), suggesting ingress of young-of-the-year fish.

Specimens were collected in Chincoteague Bay and near Wachapreague on the Virginia Seaside Within Chesapeake Bay they were taken just north of Cape Charles City, at Kiptopeke, near Fort Wool, and off the mouth of Back River. Five unverified gags were reported taken by sport fishermen at the Virginia Beach steel pier and one specimen was trapped in an eel pot at Gloucester Point. All other records except the fish from the mouth of Back River are represented by specimens.

Lengths taken (Table 1) suggest rapid growth if

---

[1] Contribution from the Virginia Fisheries Laboratory, No. 101.

TABLE 1.—Records of the gag, *Mycteroperca microlepis*, in Virginia, 1960.

Location	Capture Method	Date	Fork Length, mm	Standard Length, mm
1. The Gulf, near Cape Charles	Oyster tray	8 July	61	49
2. Wachapreague, boat basin	Minnow trap	28 July	83	71
3. Cockle Point, Chincoteague Bay	Oyster tray	3 Aug.	94	79
4. Cockle Point, Chincoteague Bay	Oyster tray	3 Aug.	104	84
5. Cockle Point, Chincoteague Bay	Oyster tray	3 Aug.	110	90
6. Cockle Point, Chincoteague Bay	Oyster tray	3 Aug.	112	92
7. Swash Bay, Virginia Seaside	Oyster tray	9 Aug.	116	94
8. Killick Shoal, Chincoteague Bay	Crab pot	10 Aug.	150	125
9. Kiptopeke, ferry terminal pier	Hook & line	26 Aug.	148	119
10. Wachapreague, boat dock	Hook & line	5 Sep.	161	132
11. Fort Wool, mouth of James River	Hook & line	6 Oct.	186	156
12. Virginia Beach, steel pier	Hook & line	22 Aug.	None 2 specimens	—
13. Virginia Beach, steel pier	Hook & line	23 Aug.	None 3 specimens	—
14. Back River, mouth	Hook & line	Early Nov.	None	—
15. Gloucester Point, Virginia Fisheries Laboratory pier	Eel pot	18 Sept.	None	—

these fish were from the same year class. No annuli were seen on scales taken from the four largest specimens.

The smaller specimens were grouper-like in appearance with rounded caudal fins, and were generally dusky green with irridescent green, longitudinal wavy blotches. The median fins of Chincoteague Bay specimens were dusky green to black with lighter green blotches. The specimen from Kiptopeke closely fitted the description by Jordan and Evermann (1902:393–4). The dorsal was dark olive, with the tip of the soft dorsal blue black and narrowly edged with white. The caudal was mostly black with only a hint of blue, but with the trailing edge white. The anal was "deep indigo blue, olive at base, its edge white".

LITERATURE CITED

EVERMANN, B. W. AND S. F. HILDEBRAND. 1910. On a collection of fishes from the lower Potomac, the entrance of Chesapeake Bay, and from streams flowing into these waters. *Proc. Biol. Soc. Wash. 23:157–64.*

JORDAN, D. S. AND B. W. EVERMANN. 1902. American food and game fishes. *Doubleday, Page & Co. N. Y. 1 + 572*

SMITH, C. L. 1959. A revision of the American groupers (*Epinephelus* and allied genera) Ph.D. Thesis. *Univ. of Mich. (L. C. card No. Mic. 59-4988) Univ. Microfilms. Ann Arbor, Mich.*

H. D. HOESE, C. E. RICHARDS, and M. CASTAGNA

Virginia Fisheries Laboratory Station, Wachapreague, Virginia;
Virginia Fisheries Laboratory, Gloucester Point, Virginia; and
U. S. Bureau of Commercial Fisheries, Biological Laboratory, Oxford, Maryland (Franklin City, Virginia).

printed from "Western Fisheries"— May, 1961

rial comment by
RN FISHERIES

The Pacific Coast Tuna Fisheries

U.S. Pacific coast tuna fleets landed about 300 million pounds last year, worth $45 million dockside. The fishery is restricted by no conservation regulations, consequently is in danger of being overfished, although scientists can not yet pinpoint a maximum allowable catch. Yellowfin will likely be first to be brought under regulations, as pressure of big, efficient seineboat conversions is very great this year.

By Gerald V. Howard

The Pacific coast tuna industry ne into existence in southern Cali- nia at the turn of the present ntury. In its first years, it was ited in growth by the fact that acore was the only species market- e as a canned commodity. After tropical species gained consumer acceptance and refrigeration and larger vessels came into use, rapid expansion occurred. The 1920 pack of the several tuna species was about 20 million pounds. As the number of larger vessels increased and they ranged farther and farther south during the 1920's, the annual catch rose rapidly and, by 1930, totaled nearly 100 million pounds. In 1940, it passed 200 million pounds and a peak production of 390 million pounds was reached in 1950. The overall production of 1950 has not since been equalled, principally because prices declined steadily as a result of the flow of foreign imports. In 1960, the Pacific coast fleets landed about 300 million pounds.

TUNA FISHING AREAS
EASTERN PACIFIC

Tuna ranges along much of eastern Pacific off North and South America. Albacore occurs infrequently north of the Columbia river.

The Pacific coast tuna fishery ranks with salmon in value. The two compete for second place among United States fisheries after shrimp. Tuna landings are presently worth about 45 million dollars annually to the fishermen.

When one considers that the eastern Pacific tuna fishery has ranked high among our fisheries for more than thirty years, it is surprising that, as recently as a decade ago, knowledge of the biology and ecology of the several species was almost completely lacking. Research programs in the eastern Pacific during the last ten years have made rapid progress towards elucidating the ways of these commercially important fishes and the effect of the fishery on them.

The present intention is to review the extent of the eastern Pacific tuna fisheries, to outline the responsibilities and the activities of the several organizations concerned with tuna research and management, and to assess the research accomplishments in relation to the need.

About the Author

Gerald V. Howard is Director of the United States Bureau of Commercial Fisheries Biological Laboratory at San Diego, California.

He began his fishery research career with the International Pacific Salmon Fisheries Commission at New Westminster in 1941, after graduating from the University of British Columbia. While employed by the Salmon Commission, he completed graduate work in biology at UBC, receiving a Master's Degree in 1947. In 1948 he was appointed to the scientific staff of the Fisheries Division of the Food and Agriculture Organization of the United Nations in Washington, D.C. When that organization transferred its headquarters to Rome, Italy in 1951, he accepted a position as Senior Scientist with the Inter-American Tropical Tuna Commission, La Jolla, California, which was then beginning its research on the tunas of the eastern tropical Pacific.

Howard remained with the Tuna Commission until March, 1959, when the Bureau of Commercial Fisheries established the San Diego Biological Laboratory.

THE FISHERIES

Four species of tuna support the nited States Pacific coast tuna fish- ies. They are albacore, *Thunnus rmo;* bluefin, *Thunnus saliens;* ipjack, *Katsuwonus pelamis;* and llowfin, *Neothunnus macropterus.* mall catches of a fifth species, big- e, *Parathunnus sibi,* are included yellowfin but amount to less than ie percent of total yellowfin land- gs. The year-round fishery for yel- wfin and skipjack, the tropical nas, extends from southern Cali- rnia to northern Chile and offshore veral hundred miles. The seasonal heries for albacore and bluefin us- lly begin in June — that for alba- re usually in the vicinity of Cedros d Guadelupe Islands off Baja Cali- rnia, Mexico, and that for bluefin equently somewhat further south ear Cape San Lazaro. As the sum- er progresses, both fisheries move the coast. More often than not, e albacore fishery extends as far rth as Oregon where it terminates October or November. In some ears, albacore are caught off the ast of Washington and, occasion- ly, they are taken off British Col- nbia Bluefin have never been ught in commercial quantities rth of Point Conception, Califor- a. The geographic extent of the heries for the four species is out- ned schematically in the accom- nying diagram.

The tropical species make up near- eighty percent of the landings. Small vessels, averaging about forty feet overall length, many of which also fish for salmon, land the bulk of the albacore. Trolling and live-bait fishing methods are used to catch albacore. Bluefin are taken exclusively by purse seiners. Large long-range seiners, as well as smaller local craft which also engage in sardine and mackerel fishing, land this species. Most of the yellowfin and skipjack are taken by long-range bait boats, which practice pole and line fishing with live bait, and by purse seiners, which use nets exclusively. Until 1959, bait boats dominated the tropical fishery. Mass conversion of bait boats to purse seiners, like *West Point* shown in the pictures, in 1959 and 1960, brought about by introduction of the power-block and the nylon net, has completely changed the complex of the tropical fleet. Today, there are about twice as many seiners as bait boats and the proportion favoring the seiners will increase.

Table I provides data on quantity and value of tuna landed at United States Pacific coast ports each year since 1950. San Pedro is by far the most important west coast port for canning of tuna; it is followed by San Diego, which is the home port of the majority of the long-range tuna vessels.

The number of small albacore vessels is not well documented. It is variously estimated that about 3000 were engaged in the fishery ten years ago and that less than 1000 now remain active. Make-up of the long-range bait boat and seiner fleets, consisting of vessels with capacities of 60 to 600 tons, catching the tropical tunas is well known. The average size of the fleet, 1950-1961, and the relative importance of the two fishing methods are indicated in Table 2.

Table 2

United States Based Long-range Vessels Engaged in the Eastern Tropical Pacific Tuna Fishery during the Years 1950-1961

Year	Bait Boats	Purse Seiners	Total
1950	204	67	271
1951	225	78	303
1952	202	64	266
1953	190	64	254
1954	182	69	251
1955	172	63	235
1956	175	64	239
1957	170	50	220
1958	159	44	203
1959	140	53	193
1960	70	83	160
1961 1/	48	98	146

1/ *As of January 1961. Does not include nine bait boats under conversion to seiners. Table includes Puerto Rico-based vessels but not some seventeen U.S. flag vessels operating from foreign ports.*

Source: Inter American Tropical Tuna Commission.

Table I

Tuna Catch, United States Pacific Coast States, 1950 - 1960

(in thousands of pounds and thousands of dollars)

	Albacore		Bluefin		Skipjack		Yellowfin		Total	
ear	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
50	72,453	13,839	2,762	426	126,786	18,131	187,890	28,823	389,891	61,219
51	34,491	5,403	3,862	604	116,599	16,655	161,481	24,961	316,433	47,623
52	52,558	9,146	4,577	733	84,844	10,908	178,819	28,275	320,798	49,062
53	34,700	6,920	9,773	1,550	122,978	16,943	133,340	21,313	300,791	46,726
54	26,998	5,426	21,025	3,553	153,756	23,345	119,402	20,575	321,181	52,899
55	29,738	4,826	13,609	1,941	102,807	13,799	123,208	18,869	269,362	39,435
56	41,338	7,082	12,626	1,650	123,717	14,189	150,923	20,369	328,604	43,290
57	46,659	6,732	20,315	2,417	90,821	9,991	137,240	18,194	295,035	37,334
58	38,445	7,897	30,719	4,029	123,372	14,239	123,727	16,727	316,263	42,892
59	46,300	8,200	16,500	2,400	110,900	12,000	108,900	14,000	292,600	36,600
60	39,500	-	10,900	-	55,000	-	193,700	-	299,100	-

urce: 1950 through 1957 - *United States Tuna Fishery, 1911 - 1958,* U.S. Department of the Interior, Fish & Wildlife Service, Bureau of Commercial Fisheries, Fishery Leaflet 484, April 1959.

1958 - *Fishery Statistics of the United States, 1958, ibid.,* Statistical Digest No. 49, 1960.

1959 - *Fisheries of the United States, 1959 - A Preliminary Review, ibid.,* Fishery Leaflet 393, Revised, April 1960.

1960 - *Fishery Products Report P-3, ibid.,* Market News Service, San Pedro, California, January 5, 1961.

THE FISHERY AGENCIES

The fishery agencies of three Pacific coast states, California, Oregon and Washington; the Federal Government through the United States Bureau of Commercial Fisheries (San Diego and Stanford Biological Laboratories); the Inter-American Tropical Tuna Commission; and the Scripps Institution of Oceanography of the University of California are, in varying degrees, concerned with research or management of the tuna resources of the eastern Pacific. Agencies of the three Pacific coast states are responsible for the management or regulation of the harvest of albacore and bluefin. As far as the United States eastern Pacific tropical tuna fishery is concerned, its management is subject to joint action by the High Contracting Parties adhering to the Convention which established the Inter-American Tropical Tuna Commission. The State of California, however, has authority to regulate the activities of California-based vessels operating in the tropical fishery.

The principal research activities of the several organizations are summarized as follows:

Fish Commission of Oregon: The Fish Commission of Oregon has one scientist engaged full-time in albacore research who is primarily concerned with learning more about the timing of the albacore fishery off the coast of Oregon. The Commission sponsors a pre-season exploratory cruise from a chartered fishing vessel and conducts tagging of albacore during the period of the fishery.

California Department of Fish and Game: The California Department of Fish and Game, through the California State Fisheries Laboratory at Terminal Island, is actively engaged in tuna research. The laboratory recently dropped its research efforts on the tropical species to concentrate on albacore and bluefin, except that its statistical unit continues to collect and compile landing data on the tropical species through a "pink-ticket" system. Approximately five biologists and four sub-professional personnel are employed in tuna research. The objective of the research is to obtain information on which to base recommendations for such management on albacore and bluefin as is necessary. Emphasis is presently placed on collection and analysis of catch and effort data from the "pink-ticket" system and logbook records, a market sampling program, and tagging. The laboratory also conducts pre-season albacore scouting cruises with its research vessels, *N. B. Scofield* and *Alaska.*

Washington Department of Fisheries: The Washington Department of Fisheries, while not actively engaged in albacore research, conducts market sampling and interviews vessel masters to document areas of origin of their catches.

Inter-American Tropical Tuna Commission: The Inter-American Tropical Tuna Commission is charged with the responsibility of gathering and interpreting factual information to facilitate maintaining the populations of yellowfin and skipjack tuna in the eastern Pacific Ocean at a level which will permit maximum sustained catches. The United States, Costa Rica, Panama and Ecuador are presently parties to the Convention which established the Commission. Other governments whose nationals participate in the fishery covered by the Convention may adhere when they see fit. The Tuna Commission began its research in 1951 and presently employs about forty individuals of whom approximately 25 are scientists.

United States Bureau of Commercial Fisheries:

Stanford Biological Laboratory

The Bureau's Stanford Biological Laboratory was established in 1956 to pursue studies of meteorological and oceanographic conditions in the north Pacific for the purpose of relating broad-scale environmental changes in the ocean to fluctuations in the abundance and distribution of commercially important fishes, among which are the tunas. A small staff of four or five specialists in marine biology, physical oceanography, meteorology and mathematics is engaged in this work. With the completion in 1959 of a thirty-year set of indices of variations of winds over the major current systems of the north Pacific, a major effort has been exerted towards compiling monthly mean sea surface temperature charts for the period 1935-1959 and relating changes in sea surface temperatu to meteorological events.

San Diego Biological Laboratory

The Bureau established the Sa Diego Biological Laboratory in 195 to provide for the specific applic tion of oceanographic and biologic findings to the problems of the tun fishing industry. The staff of twelv of which ten are of professiona grade, is concerned alike with th tropical and temperate tunas. Whereas, the first interest of the stat agencies and the Tuna Commissio is conservation, the San Diego Laboratory seeks to obtain and disseminate information which will contribute to the improvement of tuna fishing efficiently by helping to get th fishermen on the fish quickly and i catching the fish when the school are located. Three principal invest gations are underway on a modest scale: operations research to develo an optimum fishing strategy based o the integrated experience of all segments of the several tuna fishing fleets and the results of biological and oceanographic research; oceanographic research to secure information about the tunas and their environment which will help to understand the general distribution and availability of tunas and eventually will assist fishermen to converge on areas of concentration; research to learn of the responses and behaviour of tunas to provide basic scientific information to accelerate improvement in fishing gear and methods. A good part of the laboratory's oceanographic research is being done under contract to the Scripps Institution of Oceanography.

Scripps Institution of Oceanography, University of California: Since July 1957, the Bureau has had a contract with a Scripps Institution of Oceanography for the latter to conduct oceanographic research in the sea of the tropical fishery for the purpose of identifying ocean features to which tuna react in ways that affect their availability. The three main divisions of the research are: studies of distribution and interrelationships of properties, including tuna abundance, over the entire eastern tropical Pacific; similar more detailed studies in special areas where tuna aggregat ; and development and improvement of oceanographic instrumentaion and hnique, with special emphasis on e development of unmanned chor buoys which will continuous- measure certain oceanographic and teorological properties. Such un- nned buoys will be essential for adequate monitoring of environ- ntal changes as they occur in the st area of the eastern Pacific be- use the cost of obtaining the neces- y coverage from research vessels prohibitive.

The Honolulu Biological Labora- y of the Bureau of Commercial heries is conducting extensive eanographic and tuna-distribution veys and life history and popula- n structure studies in the tropical itudes at and west of the offshore rder of the region we are con- ned with here. This laboratory, merly known as the Pacific Ocean- Fishery Investigations, has contri- ted greatly to our knowledge about nas. The work at this establish- nt has intimate relation to the cific coast programs through geo- phic continuity, techniques, em- yed and objectives sought.

ESENT RESEARCH EFFORT

The tuna research programs of e various groups are well defined as purpose. The state agencies and e Tuna Commission are charged h providing information necessary management, the objective being maintain the resources at levels ich will allow maximum catches r after year. No need has yet n demonstrated for regulations protect any of the tunas and none sts specifically for this purpose. ere is, however, a state regulation long standing which governs the nimum size of yellowfin and skip- k landed in California which parently stemmed from an eco- mic need.

The Bureau of Commercial Fisher- and its contractor, the Scripps titution of Oceanography, are marily concerned with the applica- n of biological and oceanographic earch results to the improvement fishing efficiency, a relatively new nture in our parts.

oth lines of research endeavor are damental to maintain and improve economic well-being of the tuna ing industry. Introduction of con- vation measures when required ures a continuing harvest. Improved harvesting efficiency is needed to meet the challenge of rising production costs and foreign competition. Let us now examine the present research effort in relation to the need.

Research for Conservation

The basic problem of conservation is to determine the condition of the fishery corresponding to maximum catch and to ascertain the current condition of the fishery. In assessing the progress made with respect to the tuna fisheries, it is useful to keep in mind Dr. M. B. Schaefer's definition of the three levels of investigation of increasing complexity which provide information for increasingly precise management. At the first level, on the basis of observation covering different levels of fishing intensity, the average relationship among fishing intensity, fish population and catch are developed. Fishery-independent environmental factors are treated as random variables. At the second level, the three components (reproduction, growth, and natural mortality) controlling the rate of natural increase are measured and related to the abundance and composition of the population. Finally, full knowledge is sought of the effects of environmental factors on the population.

With respect to conservation research on the tropical tunas of the eastern Pacific, yellowfin and skipjack, the Tuna Commission has a good understanding of the average relationship among fishing intensity, fish population and catch. The skipjack population is very large in relation to the present harvest — so large, in fact, that it is not possible to detect any effects of the fishery on the average population abundance. The yellowfin situation, however, is quite different. Catch and effort data show conclusively that the yellowfin population responds to changes in fishing intensity. The average annual maximum sustainable catch is estimated to lie between 185 and 220 million pounds, with 198 million pounds being most probable. The total catch of yellowfin from the eastern Pacific in 1960 was at a record high — approximately 233 million pounds (Pacific coast landings plus landings made in Puerto Rico, various Latin American countries and Japan), which is the second time that the catch has been above the upper limit of the estimated maximum sustainable catch. The previous record yellowfin catch was made in 1950. Should the fishing intensity continue at the same level, or increase, as seems certain, regulation of the yellowfin fishery appears imminent.

Worthy of mention is that this is possibly the first time that a research organization has had sufficient factual informatoin on which to recommend conservation measures before action is required. It points to the benefits that result when an ade-

California tuna seiner "West Point" was built in 1946 as a bait boat and converted in January, 1960. Built of steel, she is 103 ft. overall, carries a crew of 12. Her seine is 430 x 42 fathoms, hauled by hydraulically-operated power block. Carrying capacity is 240 tons. Seining is currently the most productive U.S. method of catching tropical tunas. California seiners vary in carrying capacity between 60 and 600 tons with an average being about 250 tons.

quately supported program for management purposes is established well in advance of the need.

Although the Commission is in the position to recommend sound conservation measures when they are needed, its scientists are not relaxing their efforts. They are deep in the second level of investigation defined above. Studies of population structure, reproduction, growth and natural mortality are being advanced steadily to obtain the information which will provide for more precise management than could now be offered. They are slowly pursuing their studies towards an understanding of the efforts of environmental factors on the tropical tunas but more rapid progress is desirable and this requires substantial additional funds for oceanographic research.

Knowledge about the albacore and bluefin as to the effect of fishing and an understanding of their distribution, biology, life history and ecology lags far behind what is known about the tropical tunas because there has never been anywhere near sufficient money for the research. California State Fishery Laboratory scientists are hampered even at the first level of investigation because they do not have the manpower to obtain proper documentation of catch and effort statistics. This is particularly true for the albacore fishery because so many vessels participate in the fishery and landings are made at many different ports. Another difficult problem is that albacore and bluefin occur only seasonally in the area of our fishery and the albacore at least apparently belongs to a single Pacific-wide population subject to fishing in other regions. Without a clearer understanding of the distribution of the species and knowledge of what fishing takes place elsewhere on these populations, it is difficult and perhaps impossible to make real progress at the first level of investigation.

Wide year-to-year fluctuations occur in the west coast landings of albacore and bluefin (Table I). Since 1950, landings of albacore have varied from a low of 27 million pounds to a high of 72 million pounds. (Less than one ton was caught in 1933). Bluefin landings over the past ten years have ranged from a low of three to a high of 31 million pounds. The nature of the fluctuations, together with the gross catch and effort data available, have lead state scientists to conclude, and logically so, that they are not caused by our fishery but, rather, by variations in the environment. These fisheries, in an average year, are worth ten million dollars to the fishermen; it would seem that they are worthy of more research attention to determine if and when conservation may be necessary and to ensure proper action if the need ever arises.

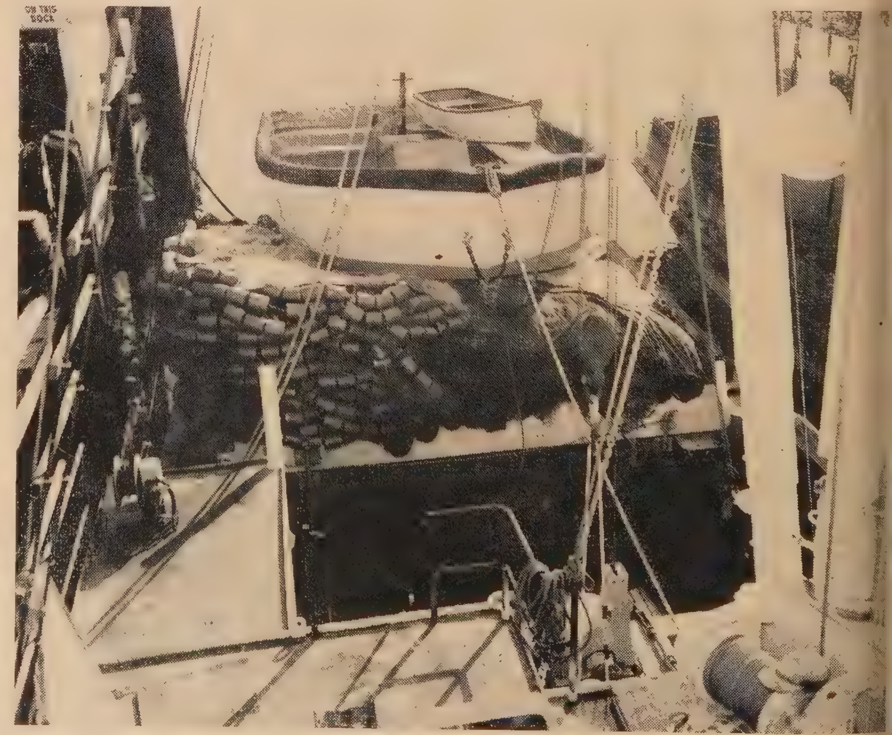
Research for Improving Efficiency

In North America, little attention is given to the application of biological and oceanographic research to improving fishing efficiency. The Japanese put this practice to good use and it seems to offer rewarding possibilities for high seas pelagic fisheries, such as for the tunas. It was with this in mind that the Bureau of Commercial Fisheries established its San Diego Biological Laboratory in 1959 and, two years before, let the first contract with Scripps Institution of Oceanography to do tuna oceanography.

Despite continuing improvements in fishing efficiency resulting from vessel and gear changes, notably those of the last two years which resulted in the mass conversion of ba boats to purse seiners, the Unite States tuna fishing industry remain in an adverse competitive positio because of its high cost of producing fish compared with that of foreign tuna fishermen. The difficult exists even though United States fishermen continue to operate more efficiently than their competitors an is a consequence of a difference i living standards.

The central problem is that o reducing production costs by shortening the time taken to catch loads o fish. Technological advances ca move only so fast and contribut only so much. It seems unlikel that they can reduce substantiall the great amount of unproductiv time spent scouting for concentrations of tuna. Scientists feel sur that biological and oceanographic research can help materially. Apparently, the industry does also, as evidenced by the support for th initiation of the studies. Since thi research is of recent origin, it is to soon to point to great accomplishment. Activity highlights will hav to suffice.

Scripps Institution of Oceanography is undertaking extensive studie on factors affecting the distribution o yellowfin and skipjack. Biological



Looking aft on "West Point." Steel seine skiff is 26 ft., seine is nylon. "West Point" uses turntable, but some late conversions have no table, set off the deck like many modern B.C. seiners.

ıemical and thermal properties of .e sea are being studied, especially the Gulf of Tehuantepec, an im-ortant area of tuna concentration in me years. Some progress has been ade towards an understanding of e circulation of the Gulf in relation the time and areas of occurrence yellowfin. The institution is also acing considerable effort on im-roving and developing equipment d instruments to follow changes the ocean and recently has had nsiderable success in advancing its velopment of unmanned buoys, hich will continuously measure cer-in oceanographic and meteorolog-al properties. Such unattended ıoys are essential for an adequate onitoring of environmental changes they occur in the vast area of the stern Pacific because the cost of btaining the necessary coverage om research vessels is prohibitive.

With respect to oceanographic re-arch, Bureau scientists at San Diego e placing their main effort on (1) amining the historical oceanograph- data collected by the California ooperative Fishery Investigation Cal COFI) in relation to variations the seasonal occurrence and dis-ibution of albacore and bluefin; 2) the preparation and distribution monthly sea-surface temperature arts for the eastern Pacific, and 3) the preparation and issuance of series of twenty-four topographic arts, or relief maps, of the ocean or of the eastern Pacific between 5° N. and 24° S. latitudes. Quick d wide distribution of the tempera-re charts to fishermen and marine ientists has resulted in favourable mments as to their usefulness in hing and for research purposes. he topographic charts are expected be useful in locating tuna which e frequently abundant around sea ounts and deeper protuberances ris-g above the sea floor, and also, to lesser degree, for navigation. The alysis of the Cal COFI oceano-aphic data and historical sea-surface mperature records shows promise our eventually being able to ac-unt for and predict some of the ide fluctuations in the albacore and uefin catches and changes in areas abundance.

Instrumentation evaluation and ex-oration is occupying the two scien-ts planning for the tuna behaviour studies. The problem is to obtain suitable instruments for observing the schooling behaviour of tuna below the sea surface. Application of sonar appears to be the most promising possibility and tests are being made at sea this spring of a sonar unit used widely in northern European fisheries. Support so far provided for the oceanographic and behaviour work has got these studies nicely under way. If they are to meet their objectives, however, funds for them will soon have to be increased. Their success depends upon research at sea and research at sea is not cheap.

Special Problems in Conservation

Two special problems face the tuna fishing industry which are worthy of mention because they relate to the matter of conservation. One will have to be met head-on by the tropical tuna fishermen as soon as the yellowfin fishery is regulated. The other, not presently as imminent, concerns problems that may arise if a substantial amount of tuna fishing is carried on in the eastern Pacific by fishermen of other nations.

The mass conversion of bait boats to purse seiners in the last two years effectively improved the economic situation of the tropical tuna fishermen. The converted vessels are about twice as efficient as they were as bait boats. Also, they apparently are able to fish selectively for yellowfin, which commands a higher price than skipjack. These two features were responsible for the record yellowfin catch in 1960 even though total landings of tropical species were lower than in the early 1960's and the fleet was only half what it was ten years ago.

Near full effect of the conversions on the yellowfin population will be felt this year and is likely to bring necessary restrictions. Regulation of the yellowfin will pose a problem for the seiners because the fleet, which has done so much better financially of late, will have to turn to the smaller skipjack, which apparently are more difficult for seiners to catch and for which there will not be the same demand as long as the canners are able to buy sufficient quantities of yellowfin from foreign sources. The alternatives are for more vessels to operate in the eastern Atlantic, as some are already doing, to learn how to catch skipjack much more efficiently, or to be able to operate to the westward of the present fishing areas.

If sufficient boats go to the Atlantic, this could forestall regulation of the yellowfin. As for fishing immediately to the westward, there is evidence that larger skipjack of very acceptable size occur in the region. We do not know, though, whether they are in quantities and concentrations to be harvested economically using present fishing methods and there is a pressing need for a research program to answer this question.

As has always been the case since the tropical fishery began, flag vessels of the United States account for most of the tropical tuna catch. Over 90 percent of the catch was taken by United States vessels in 1960; most of the remaining amount was divided among fishermen of Peru, Ecuador, Mexico, Costa Rica and Japan. The United States, Costa Rica and Ecuador, of course, are party to the Tropical Tuna Convention and, as long as the overwhelming part of the tropical catch is taken by signatories of this Convention, management of the fishery will be straightforward. Should fishing by nationals of countries not party to the Convention become substantial, it is hoped that their countries would wish to join the United States, Costa Rica, Panama and Ecuador in support of the Inter-American Tropical Tuna Commission. Should enough countries ratify the Convention on Fishing and Conservation of the Living Resources of the High Seas, prepared in Geneva in 1958, problems which may arise may be easily resolved.

Enlightened members of the tuna industry are aware that adjustments will have to be made in tropical fishing operations when conservation regulations become necessary but they see these problems as being easier to solve than those which would arise from the alternative situation — overfishing. They recognize that regulations will be based on sound scientific principles, the result of many years of research. It is hoped that there will be similar information available for the temperate tunas if and when the maximum harvest is approached, and we scientists look forward to more research on albacore and bluefin.

PRINTED IN CANADA

5

Reprinted from COPEIA, 1961, No. 4, pp. 473-475, December 19
Printed in U. S. A.

RELATIVE GROWTH OF FINS IN THE FOURHORN SCULPIN, *MYOXOCEPHALUS QUADRICORNIS,* FROM THE UPPER GREAT LAKES.—Sexual dimorphism and relative growth of body parts long have offered difficulties to fish taxonomists. These difficulties have been particularly acute in the fourhorn sculpin, *Myoxocephalus quadricornis* (Linnaeus). See Berg and Popov (1932, *C. R. Acad. Sci. U. S. S. R. 6:152–62*) for a review of the synonymy of the species and for justification for use of the present name. The fourhorn sculpin was long known to American workers as deepwater sculpin, *Triglopsis thompsoni* (e.g., Hubbs and Lagler, 1947, *Bull. Cranbrook Inst. Sci.* (*26*)*:1–186*). Jordan and Thompson (1910, *Proc. U. S. Nat. Mus. 38:75–8*) for example, were obviously unaware of the striking sexual dimorphism in this species, and the specimens figured by them as *Triglopsis ontariensis* and *T. stimpsoni* are male and female, respectively.

The relative growth of the fins of the fourhorn sculpin was studied to determine: the extent of sex differences in fin growth; the rate at which relative growth progresses; points of inflection in growth lines; whether inflection of the relative growth lines is associated with development of the gonads.

Of a total of 184 specimens examined, 134 were collected in Lake Superior in the region of Isle Royale and the Keweenaw Peninsula, Michigan, during August 1952 and May 1953; 38 were gathered in Lake Michigan off Manitowoc, Wisconsin, on June 17, 1952; and 12 were taken in Lake Huron in the vicinity of Harbor Beach, Michigan, on September 16, 1952. The collections were made from the research vessel *Cisco* of the Ann Arbor Biological Laboratory, Bureau of Commercial Fisheries. The specimens were preserved in 10-per cent formalin and later soaked in water and transferred to 70-per cent ethyl alcohol.

The relative growth of the fins was investigated by plotting the lengths of the longest rays (measured from their structural bases to their tips) and the standard length of the fish on logarithmic paper and fitting the best straight lines through the points by inspection. These lines are representative of the relative growth of the body part considered (Huxley, 1932, Problems of relative growth. *London, Methuen & Co. Ltd. 276 pp.*). Data for sexually undeveloped fish fell along the same straight line as those of mature females. The immature individuals were those in which the sex could be determined only by histological examination of the gonads; the largest fish in this group was 40 mm long. The relative growth lines of mature males (largest fish, 139 mm) were plotted separately, and were superimposed upon those of the juveniles and the larger females.

The number of specimens employed to determine the slope of the growth lines of the various fins, ranged from 47 to 52, depending upon the

Table 1. Growth Constants and Points of Inflection in the Relative Growth of Fins in *Myoxocephalus quadricornis* of Lakes Superior, Michigan, and Huron

Fin	Slope of growth line		Standard length of males at inflection of growth line (mm)
	Mature males	Mature females and both sexes at 40 mm and less	
Second dorsal	2.02	1.19	40
Pelvis	1.59	1.20	42
Anal	1.48	1.18	41.5
First dorsal	1.45	1.24	31
Pectoral	1.17	1.04	37
Caudal	1.00	0.94	39

number of points that were necessary to establish the slopes of the lines satisfactorily. The specimens included some individuals from all localities in which collections were made. The scatter of the points representing measurements of fish captured in Lakes Superior, Huron, or Michigan, exhibited no pronounced differences.

The relative size of the caudal fin remained constant in mature males (slope of 1.00—Table 1) and decreased slightly with increase of fish length among immature fish and adult females (slope, 0.94). The relative lengths of all other fins increased, however, with increase of length in both groups of fish. The rate of increase varied widely from fin to fin but without exception was decidedly greater for mature males than for females and immature males.

The slope of the relative growth line in mature males was greatest for the second dorsal fin (2.02—also see Fig. 1), had values between 1.59 and 1.45 in the pelvic, anal, and first dorsal fins, but was only 1.17 for the pectoral fin. For mature females and immature fish the growth constants ranged between 1.24 (first dorsal) and 1.04 (pectoral).

The females and immature sculpins differed from mature males further in the failure of the second dorsal fin to exhibit a much larger growth constant than any other fin. The slope of 2.02 for the relative growth line of the second dorsal of mature males was much greater than that for any other fins. The slope for the second dorsal of immature fish and adult females (1.19) was similar to that for the pelvic, anal, and first dorsal fins. In neither the mature males nor the immature fish and mature females was there any clear indication of a correlation between relative growth rate and position of the fin along the longitudinal axis.

The conformity of the relative growth of fins in immature males with that of females (mature and immature) proves that the relative growth of fins of males undergoes an inflection at about the length of fish at which sex could be determined by visual inspection. Thus, the accelerated growth of fins of males sets in at attainment of maturity. The estimates of the length of fish at the inflection of the relative growth line range from 31 mm for the first dorsal fin to 42 for the pelvic fin (Table 1). Five of the 6 estimates fall within the range of 37–42 mm and 4 are from 39 to 42 mm. No judgment is offered as to the extent to which the variation in estimates of point of inflection may reflect true differences in the course of relative growth of the various fins.

The relative growth of the fins in *Myoxocephalus quadricornis* is unusual not only for the high values of the growth constants (especially in mature males) but also for the persistence of a substantial departure from isogonic growth to the greatest lengths of fish in the samples. Any considerable deviation of a growth constant from unity leads to pronounced changes of body proportions. If the heterogonic growth is maintained over a sufficiently long interval these changes can approach the monstrous. Such a situation holds for males of the sculpin (Fig. 2), which at greater lengths exhibit second dorsal fins whose posterior tips extend al-

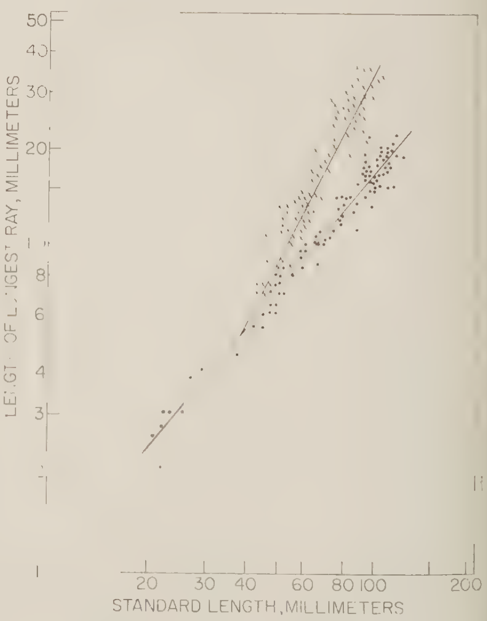


Fig. 1. Relationship between standard length of fish and length of the longest ray of the second dorsal fin in *Myoxocephalus quadricornis* in Lakes Superior, Michigan, and Huron. The crosses give values for individual mature males; the dots for females at 40 mm and greater, and for sexually undifferentiated individuals at shorter lengths. The two lines were fitted by inspection.

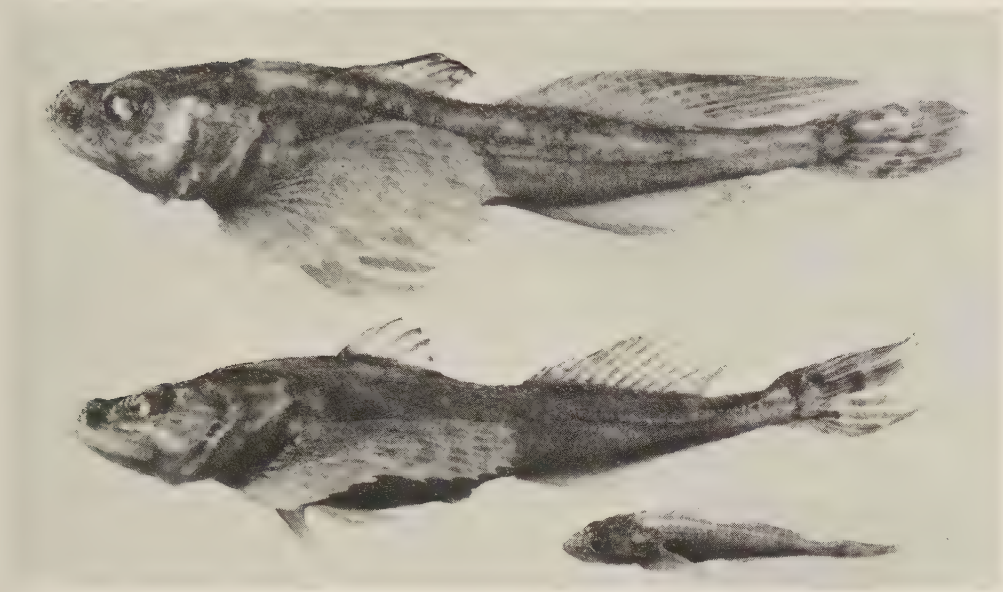


Fig. 2. Mature male fourhorn sculpin (141 mm, top), mature female (140 mm, center), and small male (54 mm, bottom). The small male was the shortest fish suitable for photographing available in the collections. All 3 fish were caught in Lake Michigan at 50 fathoms off Grand Haven, Michigan, Oct. 21, 1961. [Photograph by William Cristanelli]

most to the tip of the tail. The proportions in large females are much less extreme but large fish of both sexes exhibit sharp differences from the small, immature sculpins.—CARL JACOBY, *Ann Arbor Biological Laboratory, Bureau of Commercial Fisheries, Ann Arbor, Mich.; present address: 2216 Stanbridge Ave., Long Beach, Calif. Contribution from the Department of Fisheries, the University of Michigan, and the Ann Arbor Biological Laboratory, U. S. Bureau of Commercial Fisheries.*

51

Recaptures of Tagged Spiny Dogfish, *Squalus acanthias*

ALBERT C. JENSEN

Reprinted from COPEIA, 1961, No. 2, pp. 228-229, June 19
Printed in U.S.A.

Reprinted from COPEIA, 1961, No. 2, pp. 228-229, June 19
Printed in U. S. A.

RECAPTURES OF TAGGED SPINY DOGFISH, *SQUALUS ACANTHIAS*.—The migratory nature of the spiny dogfish, *Squalus acanthias* Linnaeus, is well known to fishery biologists. The seasonal migrations in the Northwest Atlantic have been described by Templeman (1944, *Res. Bull. Div. Fish. Resour. Newfoundland (15):1–102*) and Bigelow and Schroeder (1953, *Fish. Bull. U. S. Fish and Wildl. Serv. 53(74):47–51*). These authors suggested there is a general movement northward in the spring and early summer, and a general movement southward in the autumn. Bigelow and Schroeder (*op. cit.*) also reported that it now seems certain that spiny dogfish overwinter chiefly in the deeper water offshore. This suggests the possibility of an inshore-offshore migration.

Spiny dogfish have been tagged at sea whenever feasible during our research cruises. This note is a progress report of the dogfish recoveries to date. In July 1956, 155 specimens were tagged with Petersen discs attached with stainless steel pins through the snout. The fish were released in two locations in the Gulf of Maine; two miles south of Boon Island, Maine, and 18 miles northeast of Cape Ann, Massachusetts. In October 1957, 50 dogfish were similarly tagged and released on Browns Bank, 57 miles south of Cape Sable, Nova Scotia.

TABLE 1.—RETURNS OF TAGGED SPINY DOGFISH, *Squalus acanthias*.

Date and locality of		Weeks at liberty	Distance (miles)
Tagging	Recapture		
July 7, 1956 Boon Island, Me. (43°05′N–70°28′W)	July 22, 1957 Cape Ann, Mass. (42°44′N–70°19′W)	54	22
July 7, 1956 Boon Island, Me. (43°05′N–70°28′W)	July 29, 1959 Cape Elizabeth, Me. (43°28′N–70°12′W)	159	26
July 7, 1956 Boon Island, Me. (43°05′N–70°28′W)	July 21, 1960 Cape Elizabeth, Me. (43°27′N–70°12′W)	210	25
July 8, 1956 Cape Ann, Mass. (42°48′N–70°15′W)	Nov. 15, 1956 Cape Elizabeth, Me. (43°28′N–70°10′W)	18	40
July 8, 1956 Cape Ann, Mass. (42°48′N–70°15′W)	March 2, 1957 Cape Ann, Mass. (42°38′N–70°17′W)	34	10
July 8, 1956 Cape Ann, Mass. (42°48′N–70°15′W)	May 22, 1957 Chatham, Mass. (41°40′N–69°42′W)	48	73
July 8, 1956 Cape Ann, Mass. (42°48′N–70°15′W)	July 16, 1959 Cape Elizabeth, Me. (43°28′N–70°10′W)	157	40
Oct. 14, 1957 Browns Bank (42°36′N–65°46′W)	July 12, 1958 Chance Harbour, N.B. (44°55′N–66°21′W)	39	140

To date, eight tagged spiny dogfish (3.9 percent) have been recaptured; seven from the 1956 experiment and one from the 1957 experiment (Table 1). The length of time at liberty ranged from 18 to 210 weeks. Six fish were recaptured less than 50 miles from the tagging area while two were recaptured 73 miles and 140 miles away, respectively.

The tagged fish were recaptured relatively close to the areas in which they had been released. This is in contrast to previous tagging experiments with spiny dogfish off the coast of Newfoundland in which some of the fish were recaptured as far as 1300 miles from the point of release (Templeman, *op. cit.*; 1954, *J. Fish. Res. Bd. Canada 11(4): 351–4*, 1958, *Progr. Rep. Atl. Cst. Sta. (70):28–30.*).

The season of recapture is worthy of note in the cases of four fish recaptured at the same time of year, one to four years later. Similarly, four fish were caught in approximately the same location off Cape Elizabeth, Maine, over a span of four years, suggesting the possibility of the same fish schooling together for long periods of time.

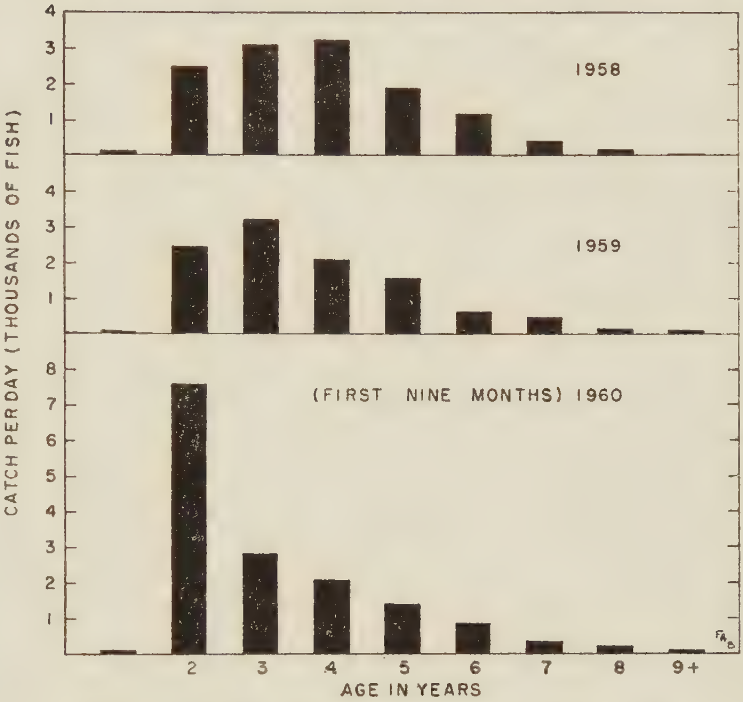
It would be presumptuous to try to draw any conclusions about dogfish migrations based on the present limited marking program. However, the tag returns received so far warrant being placed on record for the benefit of biologists who may be interested in the life history of the spiny dogfish.

The recaptures indicate that spiny dogfish return to the same general area at about the same time of year, but as yet, the limited number of returns do not confirm either a north-south or inshore-offshore migration.

Additional tagging experiments, using a plastic spaghetti tag, have been carried out since the experiments reported here. Recaptures from the recent experiments will be reported on from time to time.—ALBERT C. JENSEN, *U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts.*

Scientists Forecast Improved Catch Of Haddock On Georges During '61

By Albert C. Jensen
Fishery Research Biologist
U. S. Biological Laboratory



Graph Of 3-Year Haddock Catch On Georges Bank.

WOODS HOLE, MASS. – Prospects for the Georges Bank haddock fishery in the coming year look brighter than they have for the past couple of years.

In 1961 the abundance of marketable haddock on the bank should be moderate to good, with an increase in large haddock (over 2½ pounds) in all areas, plus an increase in scrod (less than 2½ pounds) in the South Channel area. This prediction is based on analyses of the age composition of haddock in the landings from Georges Bank (figure) and on the results of surveys conducted in 1959 and 1960 by biologists aboard the Bureau of Commercial Fisheries R/V Delaware.

The present prediction follows the one made by this laboratory in 1958. At that time, we stated that both large and scrod haddock would be less abundant during the second half of 1959 and first quarter of 1960. More scrod would become available, however, later in 1960.

The 1958 prediction was based on an abundance of young-of-the-year haddock found that year during a survey cruise of the research vessel Albatross III. The good showing of the 1958 year class as two-year-olds in the recent scrod landings thus confirmed the prediction made two years ago.

SLOWER IN '62

Although it is a little early to make a firm prediction for the 1962 haddock fishery we can say with some assurance that it probably will not be as good as the 1961 fishery, particularly for scrod.

The findings of the 1959 and 1960 groundfish surveys conducted by this laboratory suggest that the broods of haddock hatched in each of those years were smaller than the 1958 brood. Thus, there will be fewer fish entering the fishery as scrod in the second half of 1961 and 1962 respectively.

The abundance of haddock in the areas of principal interest to the New England haddock fleet—Georges Bank, the Gulf of Maine and Browns Bank — reached an all-time low in 1959 when the average catch per day (of a standard large Boston otter trawler) declined to about 8,000 pounds. This is in sharp contrast to the 1931-1958 average catch per day of about 13,000 pounds.

The drop in abundance is thought to be mainly the result of poor survival of the 1955, 1956 and 1957 broods. The 1958 brood, however, was a strong one and resulted in increased scrod landings, particularly during the second and third quarters of 1960.

Total haddock landings for 1960 (based on data collected through the month of October) should reach 80 million pounds, compared to 78 million pounds landed in 1959.

At first glance, this increase of 2 million pounds may not appear significant, but it is coupled with a decrease in effort by the fleet from about 11,000 days fished in 1959 to an estimated 7,000 days fished in 1960. More haddock were caught in 1960 with less time spent fishing for them.

(Reprinted from National Fisherman combined
with Maine Coast Fisherman, March 1961)

53

Movement of Tagged Halibut off New England—II

ALBERT C. JENSEN AND JOHN P. WISE

Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 90, No. 4, October, 1961
pp. 489–490

Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 90, No. 4, October, 1961
pp. 489-490

Movement of Tagged Halibut off New England—II

Since our previous report (Wise and Jensen, 1959), we have tagged 11 more Atlantic halibut, *Hippoglossus hippoglossus* (Linnaeus), and have received reports of 17 recaptures, for a total of 34. Two of the 17 were from the 11 recently tagged and 13 from experiments conducted in 1957. Unfortunately, two had lost the numbered discs when captured, although we suspect that one of these was tagged on Grand Manan Banks in October or November 1957.

Fish in the recent tagging operations were captured in an otter trawl and marked as follows:

Date	*Place*	*Number tagged*	*Length in centimeters*
April 1959	Browns Bank	5	38–51
	Jeffreys Ledge	3	30–56
March 1960	Browns Bank	3	46–59

One of the Browns Bank fish marked in 1959 and all of the Jeffreys Ledge fish were released with Lea tags anchored internally. The rest of the 1959 halibut were marked with plastic spaghetti tags. All of the 1960 halibut were released with Petersen discs secured on stainless steel wire through the dorsal musculature.

Two fish from the 1957 taggings, recaptured since the last report, were taken a very few miles from where they had been released, although they had been at large 80 and 109 weeks, respectively. One had been tagged on Browns Bank and one on Grand Manan Bank. Two other returns, a fish at large 156 weeks from the same operation, and one from the 1960 tagging out for only 5 weeks, had insufficient information about recapture location.

The 11 halibut whose movements are shown in Figure 1 were all tagged on Browns Bank. Four were recaptured on or near the Grand Bank, at least 600 nautical miles from Browns Bank, from 103 to 128 weeks after they were released. Five were caught well to the eastward on the Nova Scotian Banks, from 200 to nearly 500 miles from Browns, 50 to 113 weeks after release. Two were caught less than 100 miles from Browns Bank after being at large 113 and 128 weeks. These results are

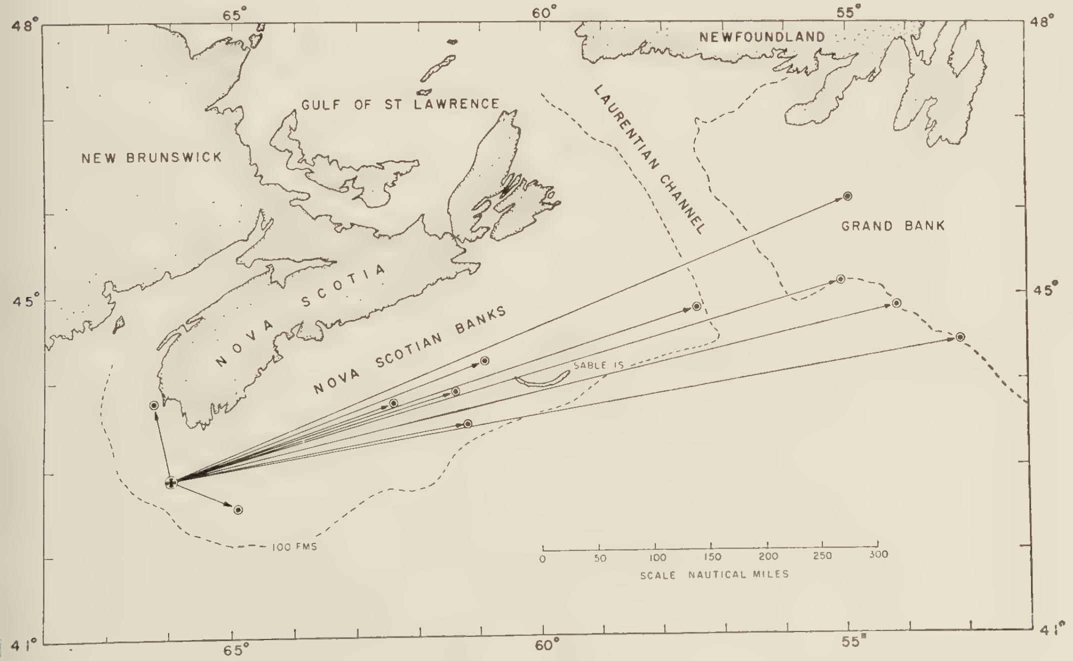


Figure 1.—Movements of halibut tagged on Browns Bank and recaptured after 50 or more weeks at large.

quite similar to those reported by McCracken (1958) from his tagging in western Nova Scotian waters in 1947, except that far fewer of his fish in number or percentage moved long distances or crossed the Laurentian Channel.

The mean length at tagging of the fish which went to the Grand Bank was 55 centimeters, of the fish which moved along the Nova Scotian Banks 45 centimeters. The mean length at tagging of the four fish which traveled relatively short distances (including the two not shown because of the scale of the figure) was 57 centimeters. This does not bear out the suggestion in our previous work that it is the larger fish which move the longer distances.

The previous conclusions about the superiority of the Lea tag for halibut still hold, since these tags used at various times and places have yielded about 28 percent returns in contrast to about 16 percent for other types, even though at the time of this writing some of the Lea tags have been out only just over a year. In addition, several letters which accompanied returned tags mentioned that the Petersen discs had become imbedded in the flesh, presumably as the fish grew, and in one case at least discovery of the tag was prevented until the fish was being cut up in a retail market, with consequent loss of information. Three of the Petersen discs have been returned with the numbered member of the pair missing, which contributed to scanty information.

In summary, since the beginning of our halibut work in 1956, 202 halibut have been tagged in the waters off New England. Thirty-four, about 17 percent, of these have been reported as recaptured. While some small numbers of halibut marked at other places have yielded larger percentages, the 79 (erroneously reported before as 78) tagged on Browns Bank in the spring of 1957 and the 68 tagged there in the fall of the same year, with 14 and 7 returns respectively, have yielded the most information about migrations of halibut, particularly long distance movements.

It is difficult to draw any definite conclusions as to movements of halibut from these results. Bigelow and Schroeder (1953) point out the contradictory nature of evidence bearing on halibut migrations in the Gulf of Maine and in Nova Scotian waters. Our present results disagree somewhat with our own previous conclusion that it is the larger fish which migrate and with Martin and McCracken's (1950) finding that halibut do not cross the deep Fundian and Laurentian Channels. It should be pointed out that in a re-examination of the data augmented by more returns McCracken (1958) found that one fish had gone from Browns Bank to the Grand Bank and one from the Gulf of St. Lawrence to Iceland.

Thus halibut of medium size or larger are capable of and do perform long migrations in the Northwest Atlantic, but whether the individual fish moves or not seems almost a matter of chance.

LITERATURE CITED

Bigelow, Henry B., and William C. Schroeder. 1953. Fishes of the Gulf of Maine. 1st revision. Fish. Bull., U. S. Fish and Wildl. Serv., 53:1–577.

McCracken, F. D. 1958. On the biology and fishery of the Canadian Atlantic halibut, *Hippoglossus hippoglossus* L. Jour. Fish. Res. Bd. Canada, 15(6): 1269–1311.

Martin, W. R., and F. D. McCracken. 1950. Movements of halibut on the Canadian Atlantic coast. Fish. Res. Bd. Canada, Prog. Repts. Atlantic Coast Stations, 50: 3–8.

Wise, John P., and Albert C. Jensen. 1959. Movement of tagged halibut off New England. Trans. Am. Fish. Soc., 88: 357–358.

Albert C. Jensen

John P. Wise

U. S. Bureau of Commercial Fisheries
Biological Laboratory
Woods Hole, Massachusetts

(Reprinted from Research Briefs, Fish Commission of Oregon, Volume 8, Number 1, August, 1961.)

The Oregon Trawl Fishery for Mink Food—1948-1957

WALTER G. JONES①
and
GEORGE Y. HARRY, Jr. ②

INTRODUCTION

Mink ranching in Oregon has developed into an important industry, particularly since World War II. With the increase in mink farming, an ocean fishery for bottom fish for mink food has evolved. In the 10-year period 1948-57 the following important questions arose concerning the otter-trawl fishery for mink food: (1) What is the total annual catch of whole fish by species landed for mink food? (2) What are the size composition and numbers of the three principal fillet soles (Dover sole, *Microstomus pacificus;* English sole, *Parophrys vetulus;* and Petrale sole, *Eopsetta jordani*) delivered for mink food markets? and (3) What are the effects of the mink food fishery on the production and economics of the Oregon trawl fishery?

HISTORY OF THE MINK FOOD FISHERY

The first Oregon mink ranch was established about 1925. During the early years of the industry there was no otter-trawl fishery for marine bottom fish in Oregon waters. Ranchers relied on sources of red meat such as horse meat and young dairy calves for the main protein constituent of the mink diets. Gradually certain species of fish such as starry flounder (*Platichthys stellatus*), caught incidentally by salmon gill netters, Columbia River smelt (*Thaleichthys pacificus*), and carp (*Cyprinus carpio*) were included in mink rations. It was not until there was a shortage of red meat during World War II that ocean fish came into general use by most mink ranchers.

After a decline in the numbers of mink raised by Oregon ranchers during World War II (approximately 56,000 animals in 1945), production increased to a total of about 250,000 mink in 1957. The value of pelts produced in 1957 was over $4,000,000.

Development of the Oregon trawl fishery during World War II made an inexpensive source of protein available to mink ranchers in the form of fish carcasses from fillet processors. Mink ranchers west of the Cascade Mountains used fillet scrap, supplemented with some whole fish, for as much as 80 per cent of the mink rations.

A sharp decline in the fillet market fishery in 1953, with little recovery in the following years, caused the demand for fillet scrap to exceed the supply. As result, an extensive fishery developed for whole fish for mink food. In 1953 several trawlers fished occasionally for mink food, and a few which had lost their fillet markets fished exclusively

---

① Formerly biologist, Oregon Fish Commission; now with the U. S. Bureau of Commercial Fisheries, Ann Arbor, Michigan.

② Formerly Assistant State Fisheries Director, Oregon Fish Commission; now with the U. S. Bureau of Commercial Fisheries, Juneau, Alaska.

for mink food. In 1955 and 1956 mink ranchers purchased trawl boats and plants for catching and processing fish.

When an active otter-trawl research program began in January 1948, it became evident that information was needed on the relationship of the mink food fishery to the human food (fillet fish) fishery. Some fishermen declared that fillet fish stocks were being depleted because of their use as mink food. On the other hand, most mink ranchers and some fishermen insisted that no damage was being done since the mink food fish either had no value on the fillet market or would have been discarded at sea as too small and therefore wasted. This controversy has prevailed to the present time, although the entire trawl fleet now participates to some extent in the mink food fishery.

MINK FOOD PRODUCTION

Both whole fish and fillet scrap from the trawl fishery are sold for mink food in Oregon. Poundages of whole fish landed for mink food from 1953 through 1957 were obtained from reports filed with the Oregon Fish Commission by fish receivers. These data were compiled monthly for each vessel at each port. Before 1953 the total annual production was estimated from data received from mink ranchers on the amount of fish fed to their animals. Estimates of the total landings from 1948 to 1952 were computed from these data (Harry, 1956).

The fillet market fishery in Oregon showed a general downward trend from approximately 20 million pounds in 1948 to lows of 10 million pounds in 1953 and 1955 (Figure 1) but rose to about 16 million pounds in 1957. During this period the numbers of mink on Oregon ranches increased. Landings of whole fish for mink food rose sharply from about 2 million pounds in 1952 to 14 million pounds in 1956, when mink food exceeded fillet market landings by slightly over 2 million pounds.

Distribution of bottom fish landings of mink food among major Oregon trawl ports is given in Table 1 for 1953 through 1957. Astoria landings were 2.1 million pounds in 1953, rose to a high of 6.9 million pounds in 1956, and then declined to 3.9 million pounds in 1957. At Newport, the major portion of trawl fish received was mink food, since fillet processing was at a minimum between 1952 and 1957. Landings of whole fish for mink food at Newport ranged between 2.8 and 4.3 million pounds annually.

The establishment of processing plants by Oregon fur producers at Astoria in 1951 and at Newport in 1953 to receive only mink food was a major factor in increased landings at those ports. After 1955, most Astoria fillet plants also began receiving substantial quantities of whole fish for mink food. A similar situation developed at two fish-processing plants in Newport in 1955 and 1956.

The other Oregon trawl ports (Tillamook Bay, Winchester Bay, and Coos Bay) received only minor quantities of mink food until ranchers organized a company at Winchester Bay in 1955 to process mink food.

Combined landings at these three ports increased from about 0.2 million pounds in 1954 to almost 1.5 million pounds in 1955; in 1957 total landings (principally at Winchester Bay) approached those at Astoria and Newport (Table 1).

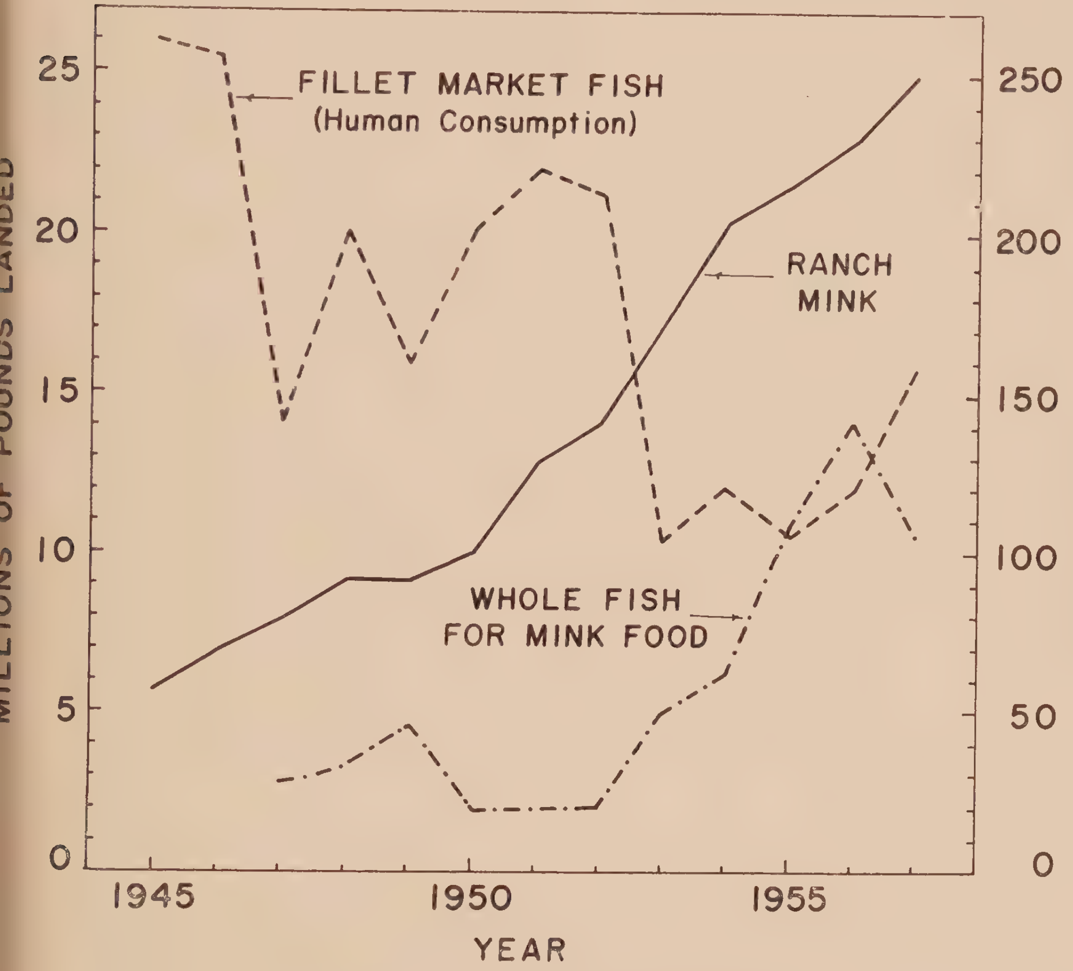


FIGURE 1. ANNUAL OREGON LANDINGS OF FILLET-MARKET FISH, WHOLE FISH FOR MINK FOOD, AND NUMBERS OF OREGON RANCH MINK, 1945-57.

TABLE 1. **WHOLE BOTTOM FISH LANDED IN OREGON PORTS FOR MINK FOOD, 1953–57.**

	LANDINGS IN POUNDS				
Port	*1953*	*1954*	*1955*	*1956*	*1957*
Astoria	2,088,000	2,400,000	5,940,000	6,855,000	3,896,000
Newport	2,813,000	3,542,000	3,558,000	4,303,000	3,469,000
Other①	76,000	197,000	1,457,000	2,963,000	3,214,000
Total	4,977,000	6,139,000	10,955,000	14,121,000	10,579,000

① Tillamook Bay, Winchester Bay, and Coos Bay Areas.

SPECIES COMPOSITION OF MINK FOOD LANDINGS

The catch of fish by otter-trawl nets usually consists of many species that are not retained for human consumption and are discarded at sea or saved for mink food. The species saved for mink food are generally not sorted and weighed separately when landed. To determine the numbers and weight of the species in the catch, it was therefore necessary to sample the landings. At the fish plant, the mink food was loaded into a box in the hold of the vessel and then hoisted to the dock. The sampling unit was a box of fish of known weight, usually about 600 pounds. One box usually was sampled from each load, although occasionally two were sampled. An attempt was made to choose each box in a non-selective manner.

The fish of each species were counted and average weights taken periodically. In most samples all Dover, English, and petrale soles were measured. Sex of these three species was determined from 1948 to 1952. After 1952, only occasional sex determinations for English sole were made.

Because mink food landings increased from 1953 through 1956, it was necessary to expand the sampling program. In each of the peak years, 1955 and 1956, approximately 90,000 fish were counted in a total of 130 samples, thus tending to give better distribution of samples by area fished. At each port, samples were combined and the percentage weight composition by species determined. These percentages were used in conjunction with total production figures to determine landings by species. The calculated landings by species at each port were combined to give the total for the state (Table 2).

TABLE 2. **SPECIES COMPOSITION OF OTTER-TRAWL LANDINGS DELIVERED FOR MINK FOOD IN OREGON, 1953–1956.**

	1953		*1954*		*1955*		*1956*	
Species	*Pounds*	*Per Cent*	*Pounds*	*Per Cent*	*Pounds*	*Per Cent*	*Pounds*	*Per Cent*
Dover Sole	547,000	11	677,000	11	759,000	7	1,700,000	12
English Sole	647,000	13	308,000	5	759,000	7	552,000	4
Petrale Sole	99,000	2	62,000	1	109,000	1	228,000	2
Bellingham Sole	348,000	7	184,000	3	217,000	2	82,000	1
Rex Sole	846,000	17	492,000	8	1,844,000	17	1,944,000	14
Turbot	1,045,000	21	1,907,000	31	4,448,000	41	4,239,000	30
Rockfishes	647,000	13	1,415,000	23	1,627,000	15	4,298,000	30
Miscellaneous Fishes	796,000	16	1,107,000	18	1,085,000	10	1,078,000	7
Total	4,975,000	100	6,152,000	100	10,848,000	100	14,121,000	100

In 1957 the sampling program was reduced and the principal objective was to determine the size composition of Dover, English, and petrale soles. The species composition of the mink food landings for the state was not calculated for this year.

Some forty species of fish were found in the mink food samples (Table 3). Six species of flatfish plus rockfishes comprised 90 per cent of the total mink food landed in most years studied.

Prior to 1953, only the percentage composition by number and weight of each species in the mink food samples was determined. Totals for the state were not computed. For these years Rex sole was dominant in the samples both by weight and numbers, except in 1948 when English sole was dominant. Second in importance, by numbers, varied by year and port among starry flounder, Dover sole, petrale sole, and Bellingham sole. Third in importance varied among Rex sole, rockfish, sand dab, starry flounder, Bellingham sole, and English sole (scientific names are given in Table 3).

Dover sole landed for mink food ranged from 0.5 million pounds in 1953 to 1.7 million pounds in 1956, or 11 per cent of the annual mink food landings. Dover sole is one of the principal flatfishes filleted in Oregon for human consumption; from 1952 through 1957, landings for human consumption ranged from 2.5 to 5.8 million pounds. Because it is in demand for both human and animal food, Dover sole has been the subject of considerable research by Oregon Fish Commission biologists and the source of controversy among fillet-market fishermen, mink-food fishermen, and mink ranchers.

TABLE 3. **FISH COUNTED IN MINK FOOD SAMPLES, ASTORIA AND NEWPORT, 1953 AND 1954.**

Common Name	Scientific Name
Flatfish	
Arrowtooth flounder, turbot	*Atheresthes stomias*
Flathead sole	*Hippoglossoides elassodon*
English sole	*Parophrys vetulus*
Rex sole	*Glyptocephalus zachirus*
Sand dab	*Citharichthys sordidus*
Rock sole	*Lepidopsetta bilineata*
Petrale sole	*Eopsetta jordani*
Sand sole	*Psettichthys melanostictus*
Bellingham sole	*Isopsetta isolepis*
Slender sole	*Lyopsetta exilis*
Dover sole	*Microstomus pacificus*
Starry flounder	*Platichthys stellatus*
Rockfish	
Pacific Ocean perch	*Sebastodes alutus*
Silvergray rockfish	*S. brevispinis*
Blackmouth rockfish	*S. crameri*
Splitnose rockfish	*S. diploproa*
Greenstriped rockfish	*S. elongatus*
Yellowtail rockfish	*S. flavidus*
Chilipepper	*S. goodei*
Black rockfish	*S. melanops*
Blue rockfish	*S. mystinus*
Bocaccio	*S. paucispinis*
Canary rockfish	*S. pinniger*
Flag rockfish	*S. rubrivinctus*
Stripetail rockfish	*S. saxicola*
Shortspine channel rockfish	*Sebastolobus alascanus*

TABLE 3—Continued.

Miscellaneous Fish

Common Name	*Scientific Name*
Shad	*Alosa sapidissima*
Eel pout	Family Zoarcidae
Jack mackerel	*Trachurus symmetricus*
Lingcod	*Ophiodon elongatus*
True cod	*Gadus macrocephalus*
Hake	*Merluccius productus*
Dogfish	*Squalus acanthias*
Tom cod	*Microgadus proximus*
Sea poachers	Family Agonidae
Ratfish	*Hydrolagus colliei*
Blackcod	*Anoplopoma fimbria*
Sculpins	Family Cottidae
Skates	Family Rajidae

English sole in the mink food landings ranged from 308,000 to 759,000 pounds in the 4-year period 1953-1956 and the proportion of the total annual landings decreased from 13 per cent in 1953 to 4 per cent in 1956. English sole is the second most valuable flatfish processed for fillets in Oregon. Since 1953, landings for the fillet markets have ranged from 800,000 to 900,000 pounds annually.

Of the three most important flatfish in the otter trawl fishery, petrale sole was in greatest demand by fillet markets. Landings for fillet processing have ranged from 0.8 to 1.1 million pounds annually since 1953. This species, however, has constituted only 1 or 2 per cent of the total animal food landings, although the poundage increased steadily from 62,000 in 1954 to 228,000 in 1956.

Arrowtooth flounder has been utilized for mink food more than any other species, primarily on the basis of diet studies conducted since 1952 with ranch mink at the Experimental Fur Farm at Oregon State University (Watt, 1951). Oregon landings increased from none in 1950 to over 4 million pounds in 1955. Arrowtooth flounder is not now landed for fillet markets, although attempts were made in 1943 and 1949 to use this species for human consumption. Large quantities are still discarded at sea from the fillet market and shrimp fisheries. This species is underutilized and production for mink food should be encouraged.

Bellingham sole is not processed for human consumption in Oregon. Although considered a desirable fish for mink, it has not been actively sought by the mink food fishery. Landings declined from 348,000 pounds in 1953 to 82,000 pounds in 1956. Generally, this fish is seasonal in appearance on the trawl grounds fished by mink-food boats.

Rex sole is first in numbers, but not in pounds, landed for mink food markets. Landings increased from 492,000 pounds in 1954 to 1,944,000 pounds in 1956, constituting between 8 and 17 per cent of the mink food total. The species appears to have a wide distribution both in depth and range along the Oregon and Washington coasts and has become increasingly important to Oregon fillet processors in recent years.

Rockfishes include about 20 species important in mink diets. Landings increased from 0.6 million pounds in 1953 to 4.3 million pounds in 1956. Most of the landings are at Newport and Winchester Bay, where fillet processing is conducted on a small scale. Five species comprise 85 percent of the rockfish landings. In order of importance, by weight, they are: *Sebastodes pinniger*, S. *alutus*, S. *paucispinis*, S. *rubrivinctus*, and *Sebastolobus alascanus.* The relative annual landings of rockfish for mink food, by species, from 1953 to 1956 are shown in Figure 2. All species listed above except *Sebastolobus alascanus* are also processed for fillets. Of these, the Pacific Ocean perch, *Sebastodes alutus,* and the canary rockfish, *S. pinniger,* are the most important. Rockfish landings for fillet markets in Oregon, exclusive of Pacific Ocean perch, ranged from 1.0 to 2.6 million pounds annually during the period 1953-56. Annual Pacific Ocean perch landings ranged from 1.6 to 3.6 million pounds during the same period.

The miscellaneous category of fishes landed for the mink food market includes 12 to 15 species, each of which generally comprised less than 1 per cent of the total annual landings, or a total of about 1 million pounds in each of the 4 years. Landings of this group decreased from 16 per cent of the total in 1953 to 7 per cent in 1956.

SIZE COMPOSITION

To understand the effect on the stocks of fish of catches of Dover, English, and petrale soles for mink food, it was necessary to know the size distribution and numbers of these species landed for both mink food and fillet markets. Measurements were taken to the nearest lower centimeter (to eliminate bias by the sampler) for most of the three species.

The following steps were taken to calculate numbers at each size-interval landed by the mink food and fillet market fisheries:

1. Numbers of fish measured at each size-interval were combined to form a length-frequency distribution.
2. Total weight landed at each port was computed.
3. Total weight was converted to total numbers by use of average weights.
4. Sample length-frequency distributions were expanded to the calculated total numbers to compute the size composition of the total landed for mink food at each port.
5. Length-frequency distributions from each port were combined to form a length-frequency distribution of the total landed in the state.

The relative length-frequency distributions of Dover sole landed for mink food during the years 1953 through 1957 and comparison of the numbers of fish landed for the mink food and fillet markets are shown in Figure 3. The minimum size of Dover sole generally accepted by Oregon fillet processors is about 14 inches.

Dover sole landed for mink food ranged from 4 to 24 inches with the

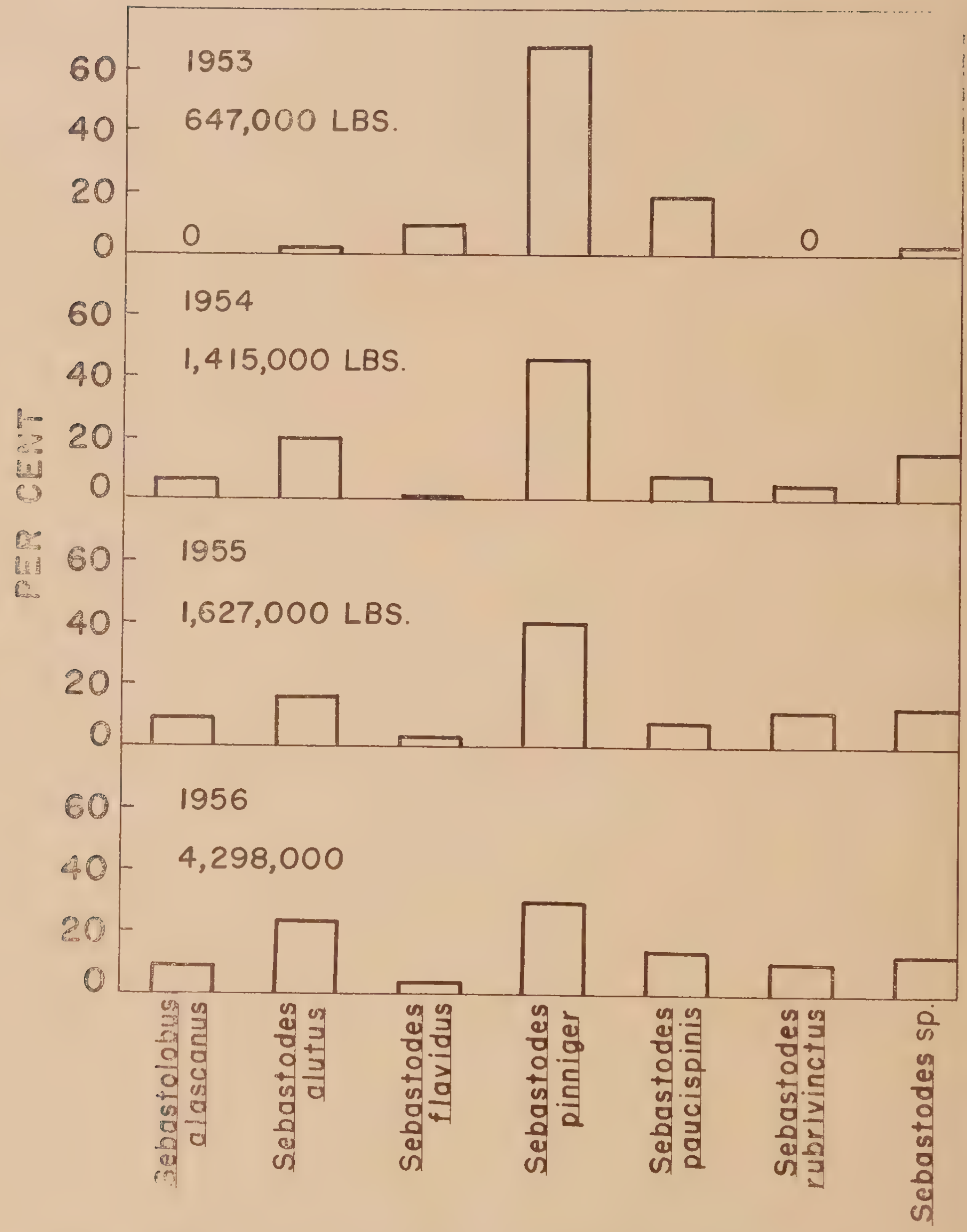


FIGURE 2. RELATIVE POUNDAGES AND PERCENTAGES OF THE MAJOR SPECIES OF ROCKFISH LANDED FOR MINK FOOD IN OREGON, 1953-56.

mode at 14. The ratio of estimated numbers of this species landed for mink food to estimated numbers landed for the fillet market varied from 1:4 in 1954 to 1:0.8 in 1956. The numbers of fish smaller than the 14-inch discard length landed for mink food increased from approximately 0.25 million in 1953 and 1954 (over 40 per cent of the total) to around 1 million in 1956 and 1957, 63 and 84 per cent, respectively.

The steady increase during the 5-year period in Dover sole landed for mink food makes it apparent that this species was actively sought for animal food. This becomes more obvious when it is considered that data from sampling catches at sea indicate that an average of about 20

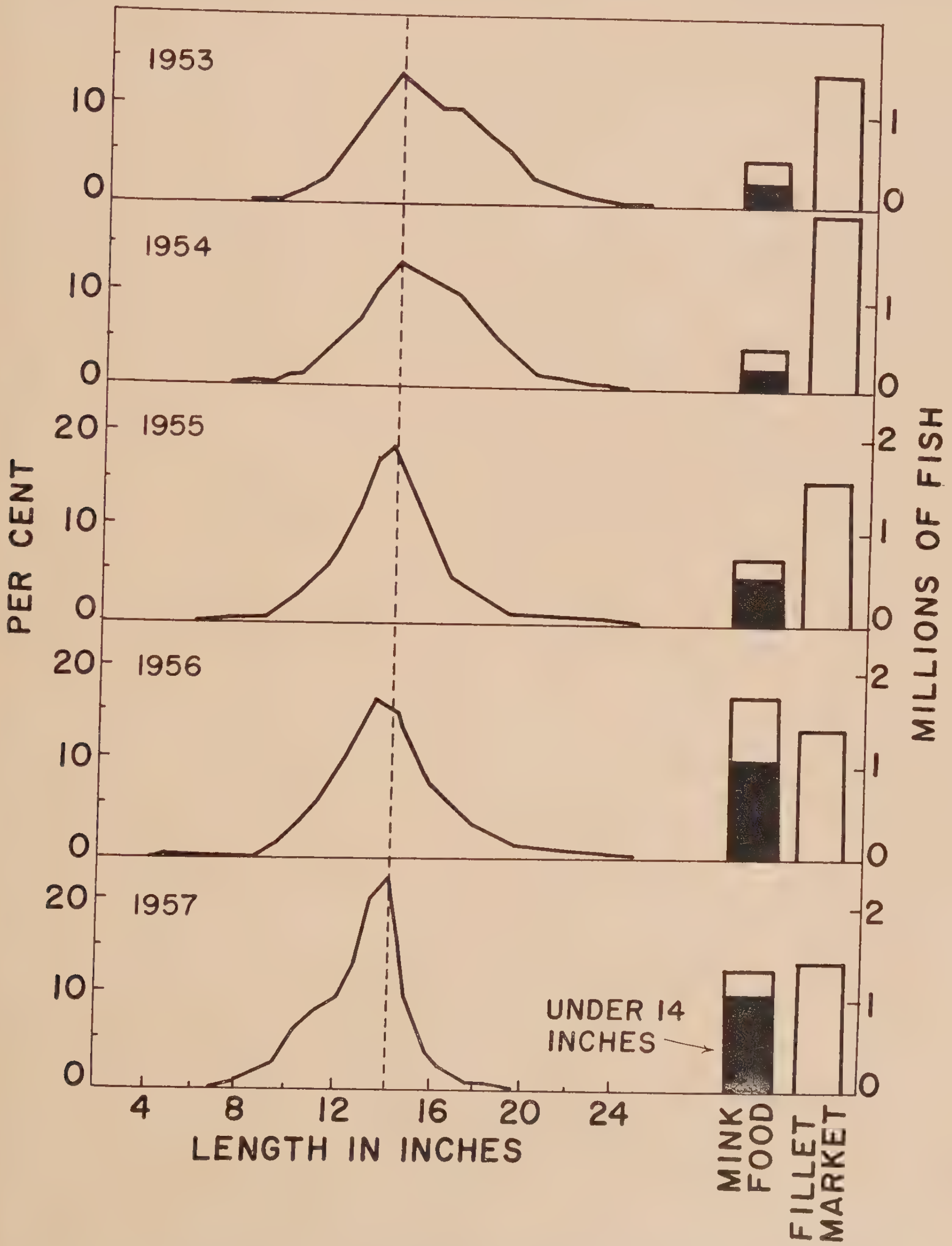


FIGURE 3. LENGTH-FREQUENCY DISTRIBUTIONS OF DOVER SOLE IN MINK FOOD LANDINGS AND NUMBERS LANDED FOR MINK FOOD AND FILLET MARKET, 1953-57.

per cent of the Dover sole caught while fishing for the fillet markets was discarded as too small. The percentage discarded, of course, varies considerably, depending on the mesh size of the net and grounds fished.

The size distribution of mink food English sole from 1953 through 1955 ranged between 6 and 22 inches with the mode at about 13, which is close to the minimum generally required by fillet plants (Figure 4). In 1956 the English sole in the mink food landings were generally larger and the mode occurred at about 15 inches. The fish were not sorted by size for use in fillet markets, but were landed exclusively for mink food, which accounts for the larger size distribution in 1956. In 1957 the mode was only about 11 inches. The decrease could have been due to sample bias, but it was more likely due to the use of the three-inch-mesh net (smaller than previously used) and the discovery by mink food fishermen that it was profitable to sort out fillet fish.

In each of the 5 years, except 1954, numbers of English sole landed for mink food equalled or exceeded those landed for fillet markets. The numbers of mink food fish smaller than the discard length of 13 inches varied between 64 and 91 per cent of the total, except in 1956 when only 20 per cent were smaller than the minimum fillet size. The generally large proportion of undersized English sole is not as important as may first appear. Male fish, which are usually smaller than minimum fillet size even when mature, outnumbered females by about 2 to 1 in the mink food samples.

Petrale sole are not as abundant as other species in the mink food landings. However, because they are intensely fished for the fillet market, adding fishing pressure may be detrimental. Therefore, close observation of the landings of petrale sole for mink food should be continued.

The size of petrale sole in mink food landings ranged between 5 and 21 inches (Figure 5). A minimum of 13 inches is imposed by fillet plants but is not rigidly observed. The modes in the mink food length-frequency distributions occurred between 12 and 13 inches, except in 1957 when the mode was about 9 inches. Between 55 and 87 per cent of the fish were less than the discard length. There was a steady increase in numbers of petrale sole landed for mink food, from 93,000 in 1953 to 342,000 in 1957. The latter figure approaches the fillet market landings.

INTENSITY OF THE MINK FOOD FISHERY

All but a few of the trawl vessels in the Oregon fleet participated to some extent in the mink food fishery during the period 1953-57. Most of the trawl boats at Newport and Winchester Bay had no markets other than for mink food during this period.

Early in the history of the fishery at Astoria, mink food was generally landed incidentally to fillet market deliveries. By 1953, some trawlers had only limited markets for fillet fish because of adverse market conditions, and by 1954 some vessels in the Astoria area were fishing exclusively for mink food at least part of the year. Others were actively seeking animal food in conjunction with fillet market fishing. A mink rancher in the Astoria area purchased a trawl boat in 1955 to fish for mink

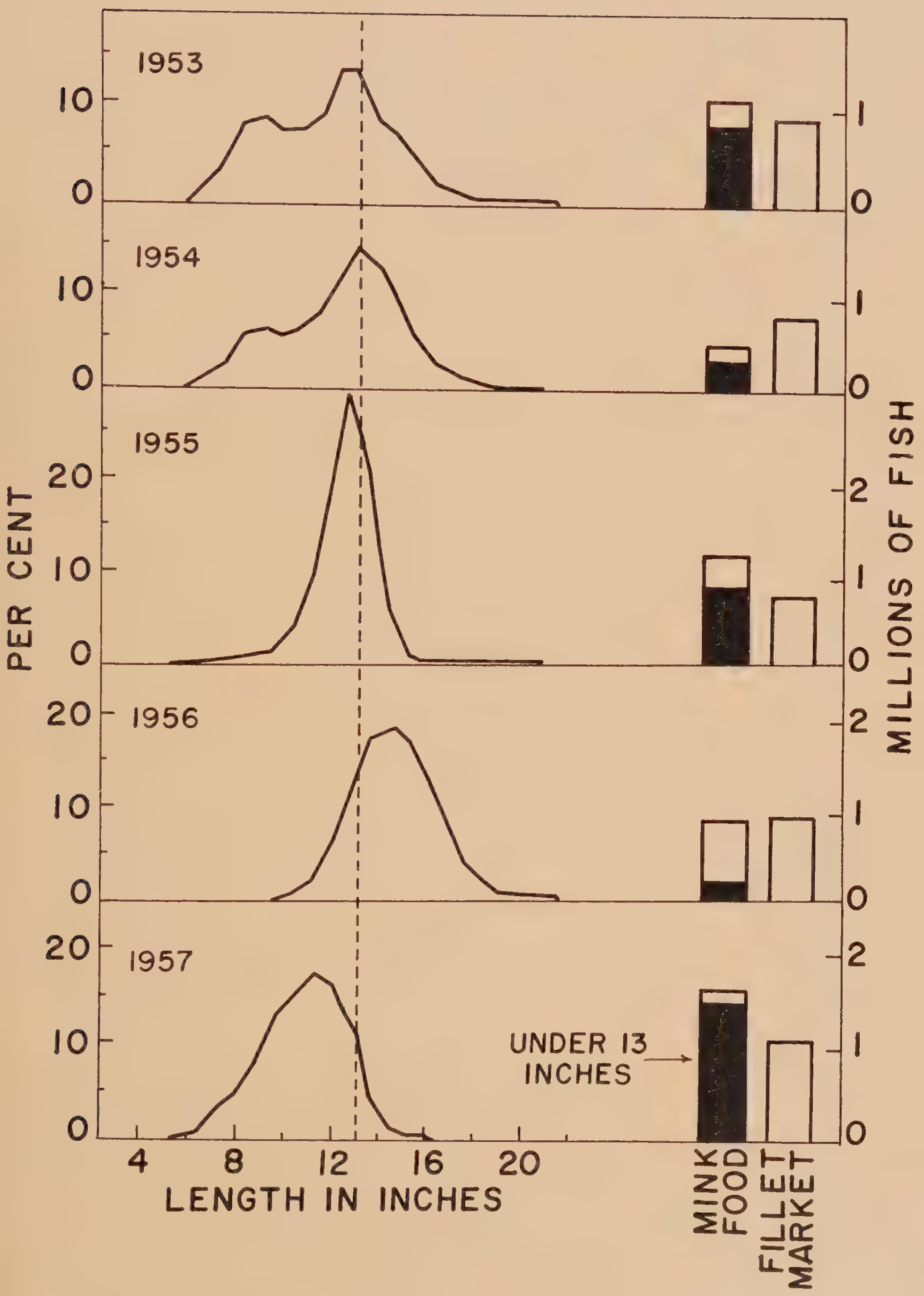


FIGURE 4. LENGTH-FREQUENCY DISTRIBUTIONS OF ENGLISH SOLE IN MINK FOOD LANDINGS AND NUMBERS LANDED FOR MINK FOOD AND FILLET MARKET, 1953-57.

food and by 1957 three other trawlers were controlled by mink ranchers, although not always used exclusively for this purpose.

During 1956, 26 of the 38 boats in the Oregon trawl fleet fished for the animal food market all or part of the time. The remaining 12 generally

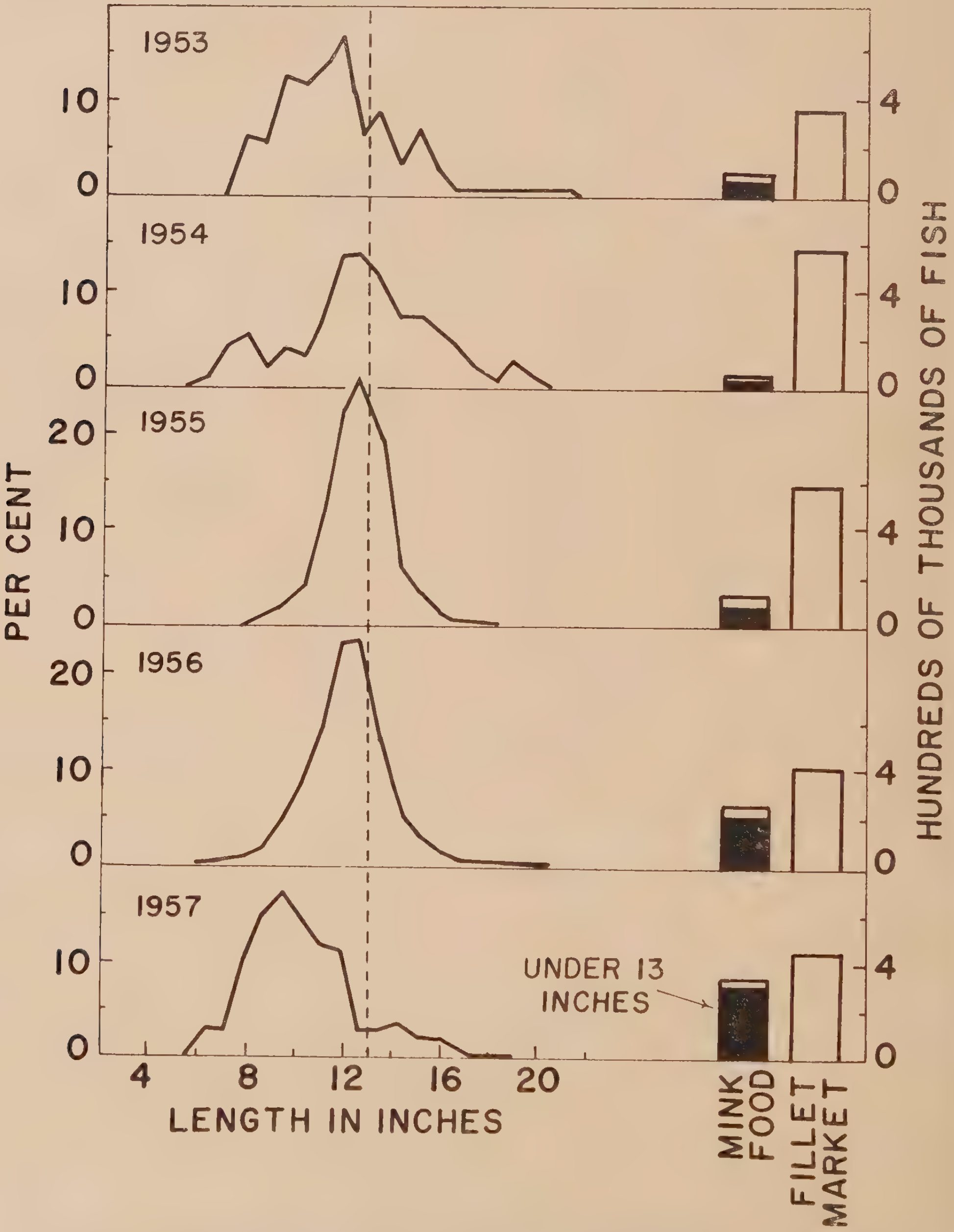


FIGURE 5. LENGTH-FREQUENCY DISTRIBUTIONS OF PETRALE SOLE IN MINK FOOD LANDINGS AND NUMBERS LANDED FOR MINK FOOD AND FILLET MARKET, 1953-57.

made landings of mink food caught incidentally while fishing for fillet markets.

Relative intensity of the mink food fishery on Oregon fishing grounds is depicted in Figure 6. Fishermen usually report the area where most of their catch was made either by sardine block number or loran and depth readings. The sardine block or grid system was adopted from the California method of dividing the fishing waters into approximately

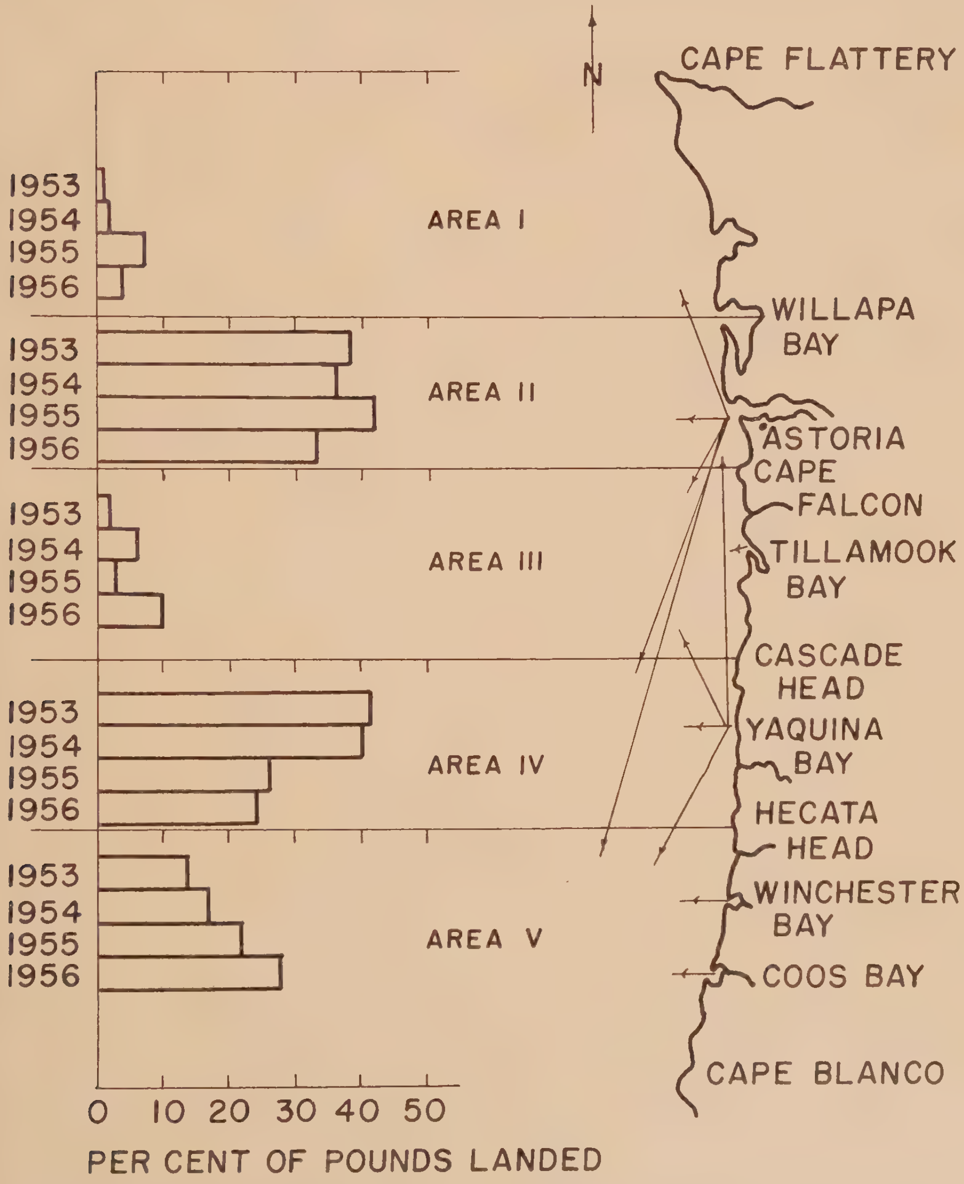


FIGURE 6. RELATIVE DISTRIBUTION, IN PER CENT, OF OREGON TRAWL LANDINGS OF MINK FOOD, BY AREA OF CATCH, 1953-56.

10-mile-square blocks, each identified by number. Several sardine blocks within a general fishing area might be fished in one trip.

For this study, fishing grounds off Oregon and Washington were defined as follows: Area I, Cape Flattery to Willapa Bay; Area II, Willapa Bay to Cape Falcon (this is called the "local" area for the Astoria fleet); Area III, Cape Falcon to Cascade Head; Area IV, Cascade Head to Heceta Head; Area V, Heceta Head to the California border.

Area I was not heavily fished for mink food by Oregon boats in any year under study. Generally, less than 5 per cent of the total pounds landed in Oregon came from this area.

Area II produced 2 million pounds of mink food in 1953 and 1954 and 4.5 million pounds in 1955 and 1956. This was about 80 per cent of the Astoria mink food landings each year and 35 to 40 per cent of the total Oregon landings.

In Area III the narrow continental shelf limits the trawling grounds, and production of mink food varied from 100,000 pounds in 1953 (2 per cent of the total) to 1,440,000 pounds in 1956 (10 per cent).

Area IV contains fishing grounds heavily utilized by Newport trawlers, particularly in 1953 and 1954 when about 40 per cent of the total landings, approximately 2.1 and 2.3 million pounds, respectively, were taken. In 1955 and 1956 landings from this area increased to 2.8 and 3.4 million pounds, respectively, but the proportion dropped to 25 per cent because of heavier fishing by Newport boats in Areas III and V.

Area V was fished by Newport trawlers in 1953 and 1954 and produced about 15 per cent (0.1 and 1.0 million pounds, respectively) of the total pounds of mink food delivered. Development of the mink food fishery out of Winchester Bay in 1955 and 1956 increased production from this area, mainly north of Cape Blanco, to 2.4 and 3.9 million pounds, respectively.

Fish for mink food brings only about half as much as that for the fillet market, and to compensate for this lower return, mink food fishermen remain close to their home ports. This accounts for the heavy fishing in areas directly off the major trawl ports.

ECONOMIC EFFECTS OF THE MINK FOOD FISHERY

The mink food fishery from 1952 through 1957 contributed substantially to the income of many Oregon trawl fishermen, and for some it was their main income. The calculated income received by trawl fishermen from deliveries of fillet market and mink food fish from 1952 through 1957 is given in Table 4. The value of fillet market fish is based on an average price of 5 cents per pound from 1952 through 1955 and 5.5 cents per pound in 1956 and 1957. Total income for fillet fish ranged from $1,065,000 in 1952 to a low of $520,000 in 1953 and then rose to $895,000 in 1957.

The amount received by fishermen for mink food increased from $156,000 in 1952 to $454,000 in 1956, then declined to $354,000 in 1957. The value of whole fish delivered for mink food was based on a price

TABLE 4. **CALCULATED INCOME RECEIVED BY OREGON TRAWL FISHERMEN FOR FISH DELIVERED, 1952–57.**

	1952	*1953*	*1954*	*1955*	*1956*	*1957*
Total Fillet Market①	$1,065,000	$ 520,000	$ 600,000	$ 525,000	$ 660,000	$ 895,000
Whole Fish Mink Food②	$ 50,000	$ 125,000	$ 155,000	$ 272,000	$ 388,000	$ 265,000
Fillet Scrap Mink Food③	$ 106,000	$ 52,000	$ 60,000	$ 52,000	$ 66,000	$ 89,000
Total Mink Food	$ 156,000	$ 177,000	$ 215,000	$ 324,000	$ 454,000	$ 354,000

① Fillet market fish value based on an average price of 5¢ per pound in 1953-55 and 5.5¢ per pound in 1956-57.

② Whole fish for mink food based on a price of 2.5¢ per pound in all years except 1956, when it was 2.75¢ per pound.

③ Fillet scrap has an indirect value. The fishermen receive approximately 10 per cent more for fillet market fish because most of the fillet scrap can be sold for mink food.

of 2.5 cents per pound in all years except 1956, when it was 2.75 cents per pound. Fillet carcasses sold for mink food add approximately 0.5 cent per pound or 10 per cent of the total value of the fillet market fish. In 1952 the value to the fishermen of whole fish delivered for mink food amounted to only 5 per cent of the value of the fillet market fish; in 1953 and 1954, 24 and 26 per cent, respectively; and in 1955 and 1956, 52 and 59 per cent, respectively. Increased landings of fillet fish in 1957 reduced the proportion of mink food income to 30 per cent.

DISCUSSION

The mink food fishery contributed substantially toward maintaining the Oregon trawl fleet at a level of about 40 vessels during the years 1952-57, stabilized employment for fishermen, and maintained businesses servicing the fleet. By the same token, communities with mink food processing plants benefited from the fishery. In fact, fishing and processing fish for mink food has become an industry in its own right in Oregon. However, as a separate industry, the mink food fishery has come into competition with the fillet market fishery, evidenced by the increasing quantities of Dover and petrale soles landed for mink food. The numbers of these species in mink food landings have closely approached or exceeded those landed for fillet markets. Most of these fish as well as English and rex sole landed for mink food are not large enough to be used by fillet markets.

No management regulations were imposed on the mink food fishery prior to 1955 since the Oregon Fish Commission felt that beneficial effects of the fishery outweighed possible detrimental effects. However, greatly increased production of mink food in 1954 and 1955 resulted in a reexamination of the problem. Studies of the stocks of Dover sole off Astoria indicated that increasing fishing pressure would impose a serious strain on this species. It was also felt that stocks of English and petrale soles could be adversely affected by increased fishing.

Consequently, in 1955, Dover, English, and petrale soles landed for mink food were limited to 20 per cent of the total poundage of each landing of mink food and fillet market fish combined. In 1956 this regulation was amended to 20 per cent of only the mink food landing and a mesh size was imposed on all the trawlers, permitting use of either 4½-inch or larger mesh (stretched measure between the knots) or 3½-inch or smaller. The small-mesh net was permitted for fishing Pacific Ocean perch.

These regulations did not prove effective in reducing the landings of the three fillet market species for animal food. Many mink food fishermen adopted the small-mesh net as an effective gear for making quantity catches of fish.

Because of the large numbers of small (less than fillet market size) Dover, English, and petrale soles landed for mink food in 1957, a regulation limiting the minimum size of these species landed for any purpose to 11 inches was placed in effect in the fall of 1958.

SUMMARY

The Oregon trawl fishery for mink food developed under the impetus of an increase in Oregon mink ranching and general decline of the fillet market fishery. Whole fish landed for mink food rose from 2 million pounds in 1950 to a peak of over 14 million in 1956, which was 2 million in excess of fillet market landings for that year.

A program was developed in 1948 to study the mink food fishery and its relationship to the fillet market fishery. It was determined that mink food landings were composed of the following species in order of importance by weight: (1) arrowtooth flounder; (2) rockfishes, a group of 20 or more species, of which the canary rockfish and Pacific Ocean perch are the most important; (3) rex sole, the species landed in greatest numbers; (4) Dover sole, an important fillet market species; (5) English sole, also valuable in the fillet markets; (6) Bellingham sole; and (7) petrale sole.

It was found that in many years most of the Dover, English, and petrale soles landed for mink food were smaller than the minimum size accepted for fillet processing and that the numbers of Dover and petrale soles delivered for mink food increased steadily until in 1956 and 1957 they approached or exceeded the numbers delivered for the fillet markets.

Almost all vessels in the Oregon trawl fleet participated to some extent in the mink food fishery during the period of this study. Some vessels fished mainly for mink food all or part of the time.

The areas fished most heavily for mink food and the ports from which the boats came were: off the mouth of the Columbia River—Astoria; off the Yaquina River and south on the Heceta Banks—Newport; and off the mouth of the Umpqua and Coos Rivers—Winchester Bay and Coos Bay.

The mink food fishery contributed substantially to the income of Oregon trawl fishermen—up to 50 per cent in some years—and permitted them better to utilize their entire catch. However, the increased intensity of this fishery could have an adverse effect on some species.

Since 1955, management regulations have been in effect to control landings of Dover, English, and petrale soles for animal food.

ACKNOWLEDGMENTS

The writers wish to thank Sigurd J. Westrheim for his assistance in the research and analysis. Among the regular and temporary Oregon Fish Commission personnel who aided in gathering and compiling data for this study were Wayne A. Burck, Denver H. Fleming, Jr., David A. Leith, Ray M. Ward, and Stanley N. Wilkes.

The cooperation of the Cregon Fur Producers Association, the Winchester Bay Fish Company, and several fillet plants is appreciated.

LITERATURE CITED

Harry, George Y., Jr.
1956. Analysis and history of the Oregon otter-trawl fishery. Ph.D. Thesis, Univ. of Wash., 328 pp.

Watt, Phyllis R.
1951. The effects of certain marine fishes in the diets of ranch mink. M.S. Thesis, Oreg. State Univ., 110 pp.

55

EXTRAIT

Rapp. et Proc.-Verb. Vol. 150, 1961
Cons. Internat. Explor. de la Mer

4.

Observations on the Behaviour, Growth, and Migration of Redfish at Eastport, Maine

By
GEORGE F. KELLY and ALLAN M. BARKER
Fishery Research Biologists
Bureau of Commercial Fisheries Biological Laboratory
Woods Hole, Massachusetts, U.S.A.

There has long been a need for better methods to resolve the questions concerning the growth and migration of *Sebastes marinus* (Linnaeus). Various growth-rates have been computed for different *Sebastes* stocks using age estimates from scales or otoliths, but there has been no direct evidence of the growth of individual fish to corroborate the estimates. Some of the computed growth-rates are so extremely low that their validity has been questioned, and in recent years a lively controversy has developed on the problem of redfish age estimation. The most promising method for obtaining the necessary information appeared to be a well designed tagging experiment.

Previous tagging attempts are known to have been made, but all had failed because of the difficulty in obtaining live fish from the deep water. Redfish are normally found in 40 to 200 fathoms in the vicinity of the Gulf of Maine, occasionally deeper to 425 fathoms (Schroeder, 1955). Fish brought up from even the shallowest of these depths are damaged by decompression and quickly die. This species seems to be more vulnerable to decompression damage than most other groundfish.

An inshore stock of redfish at Eastport, Maine, near the mouth of the Bay of Fundy, made the present study possible. The existence of this stock was first mentioned by Verrill (1871) in his descriptions of the fauna of the Eastport region. Huntsman (1922) also reported redfish in the St. Croix River and Passamaquoddy Bay. Neither record suggested anything more than an occasional appearance of small redfish in the area. On an exploratory field trip to Eastport in July 1956, fish as large as 25 cm were readily caught on hook and line. The redfish came near the surface around the docks and were caught and tagged without suffering obvious damage from decompression. Accordingly, an intensive tagging programme was designed to study growth and migration of these particular redfish.

At the present time the relationship of the Eastport redfish to other Gulf of Maine redfish is not clearly understood. The Eastport fish are considered to be a group of *Sebastes marinus* having a dark green-bronze or black tone masking the bright red colour of the typical deep-water redfish, but apparently similar to the deep-water fish in other characteristics.

The primary objectives of this study were; first, to make general observations on the behaviour of redfish, second, to obtain a direct measure of redfish growth, and third, to determine the migratory tendencies of redfish.

The topography of the Eastport shoreline consists of steep, stony beaches set between rocky outcroppings that drop off sharply into deep water. Much of the intertidal zone is overgrown with the rockweed *Fucus*. Docks are set on long wooden pilings extending out to the edge of the deep water. Numerous underwater rocky ledges line the slope of the shore beyond the mean low-water mark.

The shore is swept by strong tides causing a daily rise and fall of between 15 and 25 feet. The incoming tide from the channel north of Campobello Island presses close against the Eastport shore as it sweeps southward around the peninsula into Cobscook Bay (Fig. 1). The ebbing tide flows northward through the main channel but this northward flow does not press close against the Eastport shore. A large eddy from the ebbing tide usually predominates, causing a southward flow of water past the Eastport docks during the entire period of ebb tide.

The occurrence of redfish in Eastport harbour is apparently the result of the unusual hydrographic conditions that prevail there. The fauna of Eastport, first described by Verrill (1872), is similar to that of the offshore bottom areas of the Gulf of Maine. The westerly current along the New Brunswick coast, described by Mavor (1922), serves to concentrate pelagic fishes and invertebrates between the islands at the mouth of Passamaquoddy Bay. The euphausiid shrimp *Meganyctiphanes norvegica* appears there in vast swarms and is preyed upon by fish, whales, and sea birds during the late summer and autumn. There are no barriers to prevent redfish in the deep waters at the mouth of the Bay of Fundy from approaching the Eastport area through the deep channel at the north end of Campobello Island (Fig. 1).

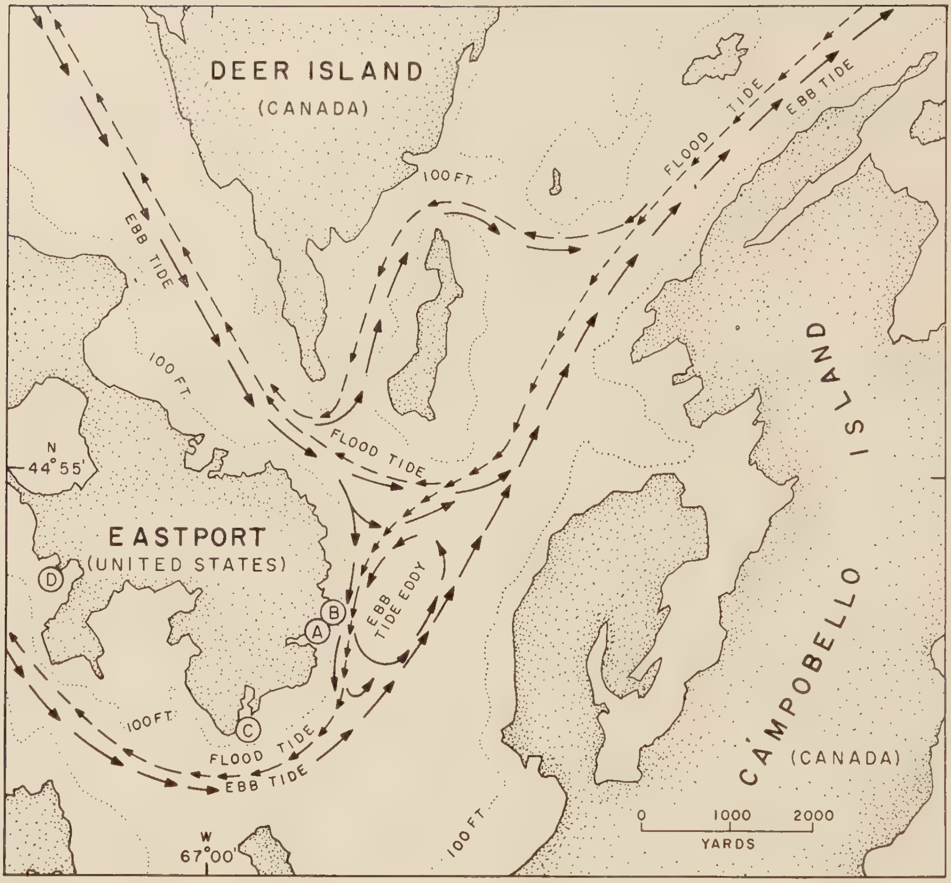


Figure 1. Tidal flow around Eastport, Maine.

Methods

Tagging operations began at Eastport in July 1956, and continued until August 1958, when the first phase of this study was completed. During that period almost 5,500 redfish were tagged. Monthly field trips were made for a year, less frequently during the remainder of the period. In July 1959 a sample of 250 tagged and untagged fish was collected for studies of the otoliths to determine the effect of tagging on the rate of growth. Redfish were collected and tagged at four locations in the Eastport area (Fig. 1). The best location was at the "old steamer dock" where, according to some of the older townsmen, redfish had appeared sporadically each summer for as long as one could remember. The location and construction of the dock apparently served to attract the redfish. It extended out into deep water farther than other docks and was built on a base of huge granite blocks set loosely together to form a wall rising about 20 ft from the harbour bottom. The wall simulated a natural rocky ledge with crevices into which the fish could move for shelter. Large electric lights set high on the dock illuminated the water, attracting swarms of shrimp to the area at night.

The bottom around the steamer dock was littered with rusting metal scraps which made the use of trawl nets impractical but did not interfere with hook and line fishing. This appeared to be the best collecting method under the circumstances. Although slow, it had the advantage of bringing fish up in good condition. Small barbless hooks were used to minimize the harmful effects of hooking. Fishing at the three alternate locations was limited to times when bad weather made it impossible to fish at the steamer dock.

Fishing was done mostly at night from a 40 ft power boat moored to the dock. The fish were held in floating live-cars alongside the boat until time for tagging. Daylight fishing was done occasionally along the channel edge about 300 yards off the dock to collect redfish from the deeper water.

The fish were tagged aboard the boat and released at the pier. A soft leather glove was worn on the left hand of the tagger to lessen the lacerations from the fin and head spines while handling the fish. Petersen disc tags were fastened to the left operculum with a red disc under the operculum and the serially numbered white disc on the outer surface, the two secured together with a stainless steel pin. Fork length was measured to the nearest millimetre.

Recaptured fish were measured and erosion damage to the operculum was noted. Tags were examined for deterioration, and faulty discs or pins were replaced.

During each fishing operation, surface and bottom water temperatures were taken with a reversing thermometer. In August 1956 a series of bathythermograph casts was made through the deep water of the channel to determine the degree of temperature stratification. At other seasons, surface and bottom temperatures were taken at two or three locations in the channel.

Results

General Observations

Cyclic variations

Activities of redfish seemed to be correlated with daily cycles of daylight and tide. Occasionally a few fish were seen and caught during the day, but usually they appeared only at night. They were most often observed and caught during calm weather, particularly on foggy or rainy nights. During windy weather when the water became choppy, redfish were virtually unavailable.

Feeding

Feeding was almost wholly nocturnal, the time varying each night with the stage of the tide. Although redfish fed primarily on the euphausiid shrimp, *Meganyctiphanes norvegica,* they were attracted to any freshly-cut animal bait. As darkness approached, a few redfish began feeding at the bottom, gradually rising during the evening until they were visible at the surface eating euphausiids. Under these conditions unwary fish were frequently taken in a dip net as they darted after euphausiids on the surface.

Redfish seemed to prefer low light intensity while feeding near the surface. When the euphausiids concentrated beneath the dock lights, redfish would feed at the edges of the illuminated area. If brighter lights were turned on, they quickly settled deeper in the water, returning again to the surface when the bright lights were extinguished.

Differences in the feeding habits of redfish and small pollack were observed when the two species were feeding together on concentrations of euphausiids. Schools of pollack darted about striking wildly at the shrimp and creating a great disturbance on the surface. The redfish fed individually, approaching the shrimp slowly and hesitatingly from beneath. With a quick, arching dart they would strike the shrimp at the surface and return below. Even when shrimp were present in vast swarms, the redfish never became frenzied but continued methodically to capture one individual at a time.

Redfish were similarly cautious when approaching a baited hook, examining it deliberately for a few seconds before gently taking it. Occasionally there was a brief competition between fish for the same bait, but usually the first fish to approach the bait was allowed to take it. The redfish did not hesitate to chase small pollack from the bait, but they did not attempt to prey on them.

Orientation behaviour

Water currents sweeping past the dock appeared to have a direct influence on activities of the redfish. The fish were most plentiful at the surface when tidal currents were at a minimum. Under these conditions the fish lay almost stationary in the water fanning their fins slowly. They might face straight up or down perpendicular to the water surface or lie tilted at an angle toward either side.

Redfish never appeared near the surface when the current was running swiftly or when the water was splashing hard against the dock. On several occasions when they were abundant in the calm water, they quickly disappeared and stopped biting when the current became swift or the surface choppy. If a pulse of swifter current swept along the dock, the fish entered crevices between the granite blocks. This action appeared to be a positive effort to avoid sudden changes in current.

When redfish came to the surface they stayed close to the face of the granite dock base and around the pilings. Their actions appeared to be part of a pattern of orientation to vertical surfaces. At times when they were almost clinging to the rocks, the dark, blotchy colour pattern served to conceal them. The whole attitude of the fish at such times suggested that this was a characteristic reaction to natural surroundings similar to what might be encountered around the rocky ledges of the offshore grounds.

Temperature tolerance

Redfish withstood temperatures higher than the approximate maximum of 48° to 50°F (8·9°–10·0°C) suggested by Bigelow and Schroeder (1953). The East-

Table 1

Summary of Eastport tagging operations listing monthly totals of catch, fishing effort, numbers tagged and recaptured, and range of water temperatures observed

Date	Water temperature		Number of			%	Number	Tagging location			
	°F	°C	days fished	fish[1] caught	tagged fish[2] recaptured	tagged fish recaptured	of tagged fish released	A	B	C	D
1956											
July	48·2–51·5	9·0–10·8	4	317	0	–	317	317	–	–	–
Aug.	50·0–53·5	10·0–11·9	11	1,789	10	0·6	1,779	1,368	–	411	–
Sept.	51·5–53·0	10·8–11·7	9	1,424	153	10·7	1,271	1,049	–	94	128
Nov.	48·5–49·0	9·7–9·4	2	102	25	25·0	18	18	–	–	–
1957											
Feb.	34·5–35·0	1·4–1·7	2	0	0	–	0	–	–	–	–
May	42·0–43·2	5·6–6·2	1	25	12	48·0	0	–	–	–	–
June	46·5–50·5	8·1–10·3	4	411	110	26·8	301	51	226	–	24
July	49·8–53·8	9·9–12·1	7	949	295	31·1	654	374	227	–	53
Aug.	51·2–55·0	10·7–12·8	7	1,043	459	44·1	585	471	109	–	5
Oct.	52·0–52·0	11·1–11·1	4	100	72	72·0	28	28	–	–	–
Nov.	49·0–49·4	9·4–9·7	2	335	162	48·4	108	108	–	–	–
Dec.	44·0–44·5	6·7–6·9	2	135	57	42·2	78	78	–	–	–
1958											
Jan.	41·2–41·3	5·1–5·2	1	1	1	100·0	0	–	–	–	–
Feb.	36·5–37·0	2·5–2·8	2	27	10	37·0	17	17	–	–	–
Mar.	37·2–38·0	2·9–3·3	3	58	30	51·7	28	28	–	–	–
May	40·7–42·0	4·8–5·6	4	128	61	47·7	67	67	–	–	–
June	44·8–46·0	7·1–7·8	3	166	126	75·9	40	40	–	–	–
July	48·5–49·5	9·2–9·8	4	361	306	84·7	55	–	–	–	55
Aug.	51·9–53·0	11·1–11·7	4	795	694	87·3	101	33	–	–	68
Totals			76	8,166	2,583	31·6	5,447	4,047	562	505	333

[1] Includes tagged fish
[2] Includes multiple recaptures

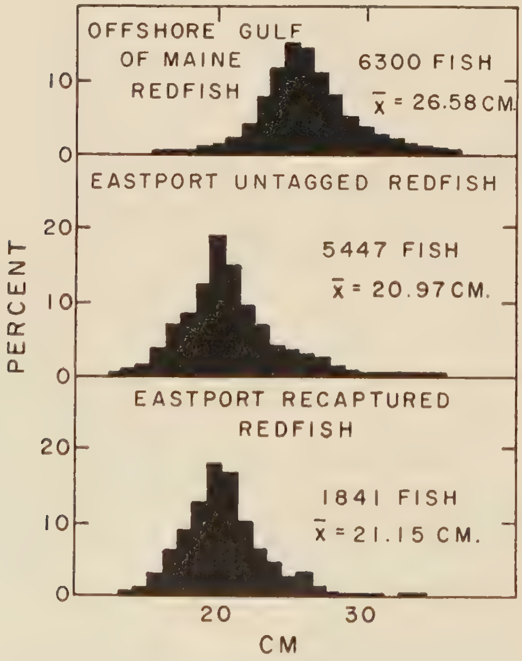


Figure 2. Length composition and mean length of offshore Gulf of Maine and Eastport redfish.

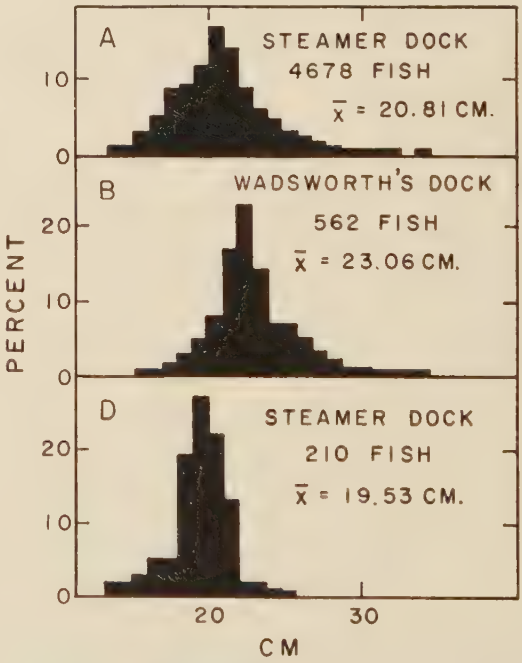


Figure 3. Length composition and mean length of untagged redfish from locations A, B, and D at Eastport.

Table 2
Length-frequency of Eastport tagged redfish at time of release

Length (cm)			1956						1957			
	July	Aug.	Sept.	Nov.	Total	June	July	Aug.	Oct.	Nov.	Dec.	Total
12·6–13·5	1	9	8	–	18	–	2	3	–	1	–	6
13·6–14·5	–	16	20	–	36	–	14	4	1	2	2	23
14·6–15·5	5	22	17	–	44	2	18	5	–	–	4	29
15·6–16·5	8	71	39	1	119	7	33	34	–	2	1	77
16·6–17·5	15	137	94	2	248	5	37	36	3	10	10	101
17·6–18·5	24	114	151	5	294	15	63	46	3	12	12	151
18·6–19·5	61	246	171	1	479	24	70	67	3	12	9	185
19·6–20·5	85	408	275	–	768	37	93	62	3	17	5	217
20·6–21·5	38	274	237	3	552	52	80	71	7	10	4	224
21·6–22·5	23	145	88	1	257	52	91	86	2	10	6	247
22·6–23·5	17	98	51	4	170	36	55	70	1	12	5	179
23·6–24·5	17	56	34	1	108	15	29	34	–	4	4	86
24·6–25·5	7	69	24	–	100	16	32	17	–	2	5	72
25·6–26·5	7	53	19	–	79	16	16	22	2	3	1	60
26·6–27·5	4	25	19	–	48	11	7	14	2	5	4	43
27·6–28·5	4	17	7	–	28	8	4	5	–	3	3	23
28·6–29·5	1	10	6	–	17	2	3	2	–	2	–	9
29·6–30·5	–	5	6	–	11	1	5	3	–	1	1	11
30·6–31·5	–	3	2	–	5	1	1	1	1	–	–	4
31·6–32·5	–	1	1	–	2	1	–	–	–	–	2	3
32·6–33·5	–	–	–	–	–	–	1	1	–	–	–	2
33·6–34·5	–	–	1	–	1	–	–	2	–	–	–	2
34·6–35·5	–	–	1	–	1	–	–	–	–	–	–	–
Number of fish	317	1,779	1,271	18	3,385	301	654	585	28	108	78	1,754
Average length	20·9	20·9	20·6	20·5	20·8	22·4	21·0	21·5	21·5	21·5	21·3	21·5

Length (cm)				1958				1956–1958
	Feb.	Mar.	May	June	July	Aug.	Total	Total
12·6–13·5	–	–	–	–	–	1	1	25
13·6–14·5	–	–	1	–	–	–	1	60
14·6–15·5	1	2	5	3	2	3	16	89
15·6–16·5	2	–	5	2	2	8	19	215
16·6–17·5	3	2	7	2	2	25	41	390
17·6–18·5	1	1	6	6	3	13	30	475
18·6–19·5	2	–	10	5	7	10	34	698
19·6–20·5	1	3	9	10	13	15	51	1,036
20·6–21·5	1	9	12	6	7	11	46	822
21·6–22·5	–	2	6	3	7	8	26	530
22·6–23·5	3	–	1	1	6	3	14	363
23·6–24·5	–	4	1	–	5	2	12	206
24·6–25·5	1	1	2	2	1	1	8	180
25·6–26·5	–	2	1	–	–	–	3	142
26·6–27·5	1	1	1	–	–	–	3	94
27·6–28·5	1	1	–	–	–	–	2	53
28·6–29·5	–	–	–	–	–	–	–	26
29·6–30·5	–	–	–	–	–	–	–	22
30·6–31·5	–	–	–	–	–	1	1	10
31·6–32·5	–	–	–	–	–	–	–	5
32·6–33·5	–	–	–	–	–	–	–	2
33·6–34·5	–	–	–	–	–	–	–	3
34·6–35·5	–	–	–	–	–	–	–	1
Number of fish	17	28	67	40	55	101	308	5,447
Average length	20·7	22·0	19·9	20·0	21·0	19·5	20·2	21·0

Table 3
Summary of numbers of redfish tagged and recaptured, July 1956—August 1958

Date	Number tagged	Number recaptured	% recaptured
1956			
July	317	203	64·0
August	1,779	918	51·6
September	1,271	397	31·2
November	18	7	38·9
1956 Total	3,385	1,525	45·1
1957			
June	301	75	24·9
July	654	141	21·6
August	585	100	17·1
October	28	0	0·0
November	108	7	6·5
December	78	4	5·1
1957 Total	1,754	327	18·6
1958			
February	17	1	5·9
March	28	6	21·4
May	67	10	15·0
June	40	7	17·5
July	55	0	0·0
August	101	0	0·0
1958 Total	308	24	7·5
Grand Total	5,447	1,876	34·4

port fish were apparently unaffected by temperatures ranging from 34·5°F in February to 55·0°F in August (1·4°–12·8°C). There was a daily summer variation of about 1°F in water temperature, the warmer water flowing from the shallow bays causing the increase at low tide. The difference between surface and bottom temperatures around the docks averaged 0·2°C. A series of bathythermograph casts through the harbour channel to the northern end of Campobello Island showed the water to be nearly isothermal at each station and progressively cooler offshore.

The approximate lethal limits of temperature for redfish were recorded during aquarium studies of fish transported from Eastport to Woods Hole. The fish withstood winter temperatures of 32°F (0°C) without showing distress. As the water cooled further, some died at about 31°F (–0·56°C) and all were killed when the water was chilled to 29·7°F (–1·28°C). During warm weather the temperature ranged between 54° and 58°F (12·2°–14·4°C) for weeks without apparent ill-effects. When it warmed to between 59° and 60°F (15·0°–15·6°C) for 4 days about 10 % of the fish died. All of these temperature changes were very gradual and the fish had some time in which to adjust to the changed conditions.

Summer water temperatures at Eastport apparently were suitable for redfish spawning. Although courtship behaviour or mating activities of adult fish were not observed, gravid females with larvae ready to be released were caught in June and July. Conditions appeared favourable for larval survival. Larvae stripped from gravid fish and placed in jars remained in good condition for hours at harbour water temperature.

Tagging Studies

Number and sizes of fish tagged

Redfish were caught and tagged during each month of the year. Greatest numbers were available in the summer with smaller numbers in spring and autumn and fewest in winter. A summary of tagging operations from July 1956 through August 1958 is shown in Table 1. A total of 5,447 redfish were tagged at four locations on the Eastport Peninsula during that time.

The Eastport redfish averaged approximately 21 cm in length, about 6 cm smaller than those landed from the nearest offshore Gulf of Maine commercial fishing grounds (Fig. 2). The size range of both groups was about the same, but there were comparatively few fish larger than 25 cm caught at Eastport. This difference is partly the result of gear selectivity, hook and line taking many small fish that would escape through the meshes of commercial otter trawls.

There was little seasonal variation in the length composition of the Eastport redfish (Table 2). Few fish smaller than 15 cm or larger than 30 cm were caught, and the mean length of daily samples was consistently between 18·5 and 21·5 cm throughout the year. Greatest differences in length composition were found among fish sampled from different tagging sites within the Eastport area (Fig. 3). The fish tagged at location A were similar in length each year. Fish caught at location B, about 300 yards from A, averaged almost 2·5 cm larger. The small numbers of fish taken at location D, about 3 nautical miles from A, were on average consistently smaller than the fish at the other locations.

Recapture of tagged fish

The successful recapture of about 35 % of all tagged redfish was, in itself, an important result of this study. It showed for the first time that redfish could be tagged and could survive to be recaptured in relatively large numbers. Almost 1,900 tagged fish were recaptured in the vicinity of Eastport, mostly at the tagging site by the investigating party (Table 3). These were measured and returned to the water unharmed, many to be recaptured again, some as often as six times. The length composition of recaptured fish was nearly identical to that of the total tagged population (Fig. 2), indicating that the collecting method was sampling all sizes of fish equally.

The percentage of tagged fish in the population at Eastport reached relatively high proportions in 1958.

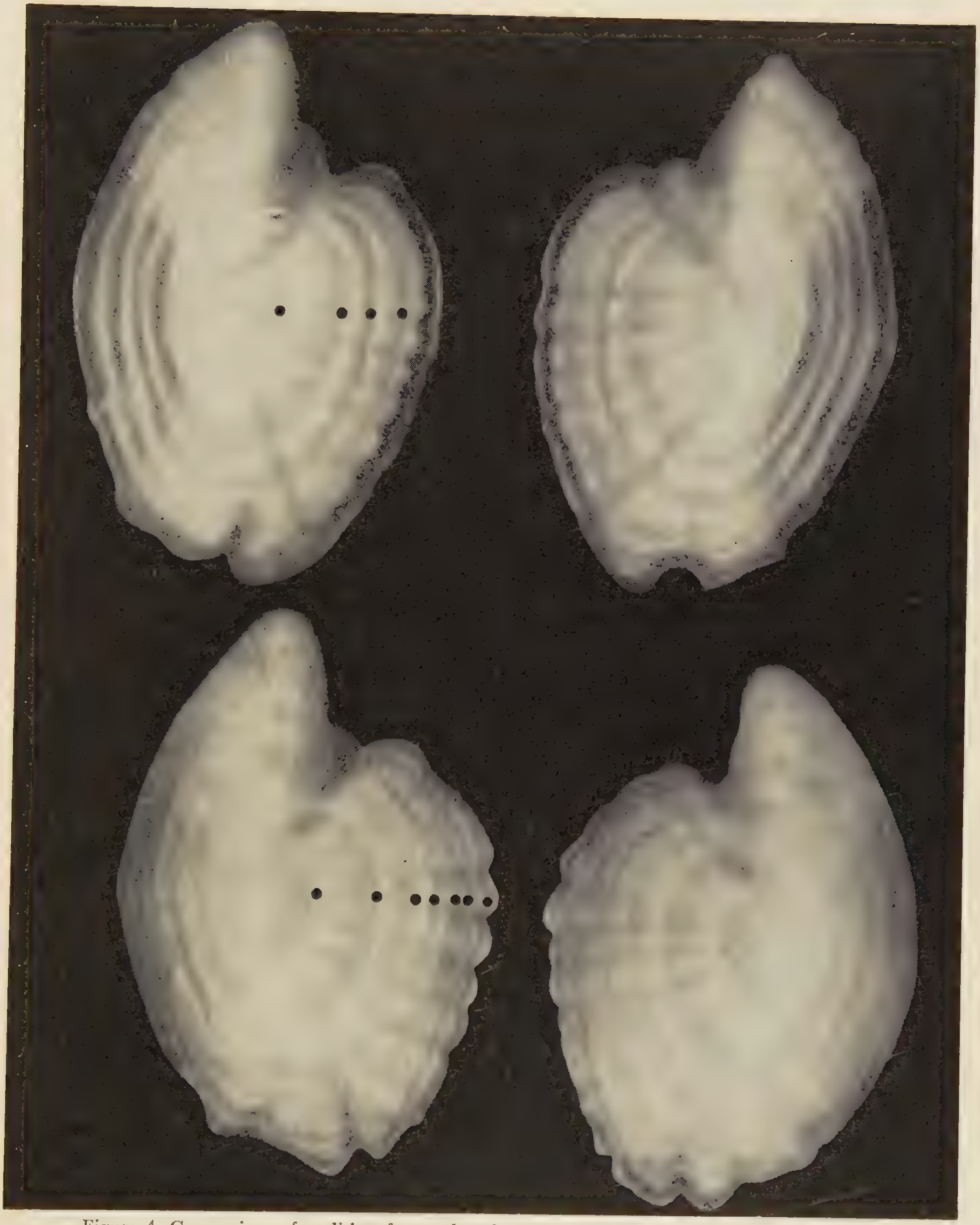


Figure 4. Comparison of otoliths of tagged and untagged redfish caught at Eastport, Maine.
Above – Male tagged 15. September 1956, length 201 mm, age 4 years plus summer growth. Recaptured 16. July 1959, length 205 mm. Wide hyaline zone at otolith edge, typical of tagged redfish otoliths, represents 34 months of diminished growth since tagging.
Below – 209 mm female caught 16. July 1959. Age 7 years plus summer growth. Normal pattern of opaque and hyaline zones is consistent throughout the otolith.

From May through August 1958, between 48 % and 87 % of the fish caught each month had been tagged (Table 1). The highest number of recaptures represented was from groups that had been at large for the longest period of time (Table 3). About 45 % of the 1956 tagging were recaptured, but only 19 % and 8 % respectively, of the 1957 and 1958 taggings have been retaken.

Growth

Preliminary comparisons of lengths at tagging and at recapture of a large number of fish indicated that the measured growth of tagged fish was slower than expected from previous studies of Gulf of Maine redfish (Kelly and Wolf, 1959). Otoliths of tagged redfish were therefore examined for evidence of changes in zone pattern that could be attributed to the effect of tagging. If the growth-rate of the fish was influenced by the tag, the normal growth pattern of the otolith should also be influenced.

Tagging zones in otoliths. In a high percentage of otoliths from tagged fish a large outer zone of hyaline material was present which differed from the obviously banded pattern of opaque and hyaline material in otoliths of untagged fish caught from the same population. The time of formation of this hyaline "tagging zone" appeared to coincide with the time of tagging. The tagging zone usually included traces of one or two thin bands of opaque material (Fig. 4).

To test the ability of the staff to distinguish otoliths from tagged and untagged fish, an unmarked sample of 155 otoliths from tagged and untagged fish was examined. More than 85 % of the otoliths were properly identified as from tagged or untagged fish by two investigators. The tagged fish had been at large for an average of 32 months, and most should have shown three winter growth zones in the otoliths. Otoliths in which tagging zones were mistakenly identified were similar to tagged fish otoliths in having a relatively large amount of hyaline material in the normal growth zones. As mentioned before, it was possible to detect traces of the opaque summer zone, but these traces were seldom clear enough to estimate correctly the number of years at large since tagging. Estimates of this sort were almost always short of the actual period of time that the fish had been tagged.

Calculated growth. Age readings of otoliths show the growth-rate of untagged fish to be approximately equal to that of tagged fish prior to the time of tagging (Figure 5). Age was read to the beginning of the tagging zone in the tagged fish otoliths and was plotted against fish length recorded at the time of tagging. Average growth of males and females in both groups was between 14·5 mm and 20·1 mm per year. The change from the normal year zone pattern in otoliths to the primarily hyaline pattern of the tagging zone suggested that after tagging growth was reduced to a very low level.

Table 4
Approximate annual length increment of tagged and untagged redfish 15 to 25 cm in length

Area	Males (mm)	Females (mm)
Eastport – Tagged	1·0	1·0
Untagged	14·5	20·1
Offshore Gulf of Maine – Untagged	20·0	24·2

Measured growth of tagged fish. The measured growth of tagged fish during the period of tagging was extremely slow. The deviations of lengths at recapture from the original tagging lengths of more than 2,500 fish are plotted in Figure 6. A regression line fitted to these deviations shows an average growth of 1 mm in a year. That this value is a small fraction of the average annual growth increment calculated for Gulf of Maine redfish is shown in Table 4.

Evidence of the slow growth during tagging is shown in more detail by the repeated measurements of fish that were recaptured and released several times (Table 5). Most of the fish grew less than 8 mm during almost two years of freedom in natural environments.

Effect of tagging on growth-rate. The great difference in growth-rate of tagged and untagged fish suggests that tagging has somehow altered the normal growth pattern of the tagged fish. The apparent effect of tagging on the growth-rate of each year-class is shown diagrammatically in Figure 7. Age readings from otoliths of tagged fish were combined with information on the lengths at tagging and recapture to obtain the average length of each year-class at tagging and at recapture. The decrease in growth-rate after tagging for all ages is dramatic. Although the young fish appear to grow slightly faster than the older ones, the growth-rates of the separate age-groups were generally less than 4 mm per year during the 3-year period of tagging.

It is impossible to say at this time how the growth of the fish is affected by tagging. Tagged fish appeared normal and healthy, apparently feeding on natural food and biting readily on cut bait. Although the tag interferes in no obvious manner with the movement of the fish's mouth, perhaps it serves to startle live prey, causing it to escape. This would reduce the quantity of live food captured and would in turn influence the growth-rate. Such starvation would probably increase the willingness of the tagged fish to take cut bait and could account for the extremely high proportions of tagged fish (85 %) that were frequently recaptured.

Summary of growth. All evidence indicates an abnormally decreased growth-rate of the tagged fish.

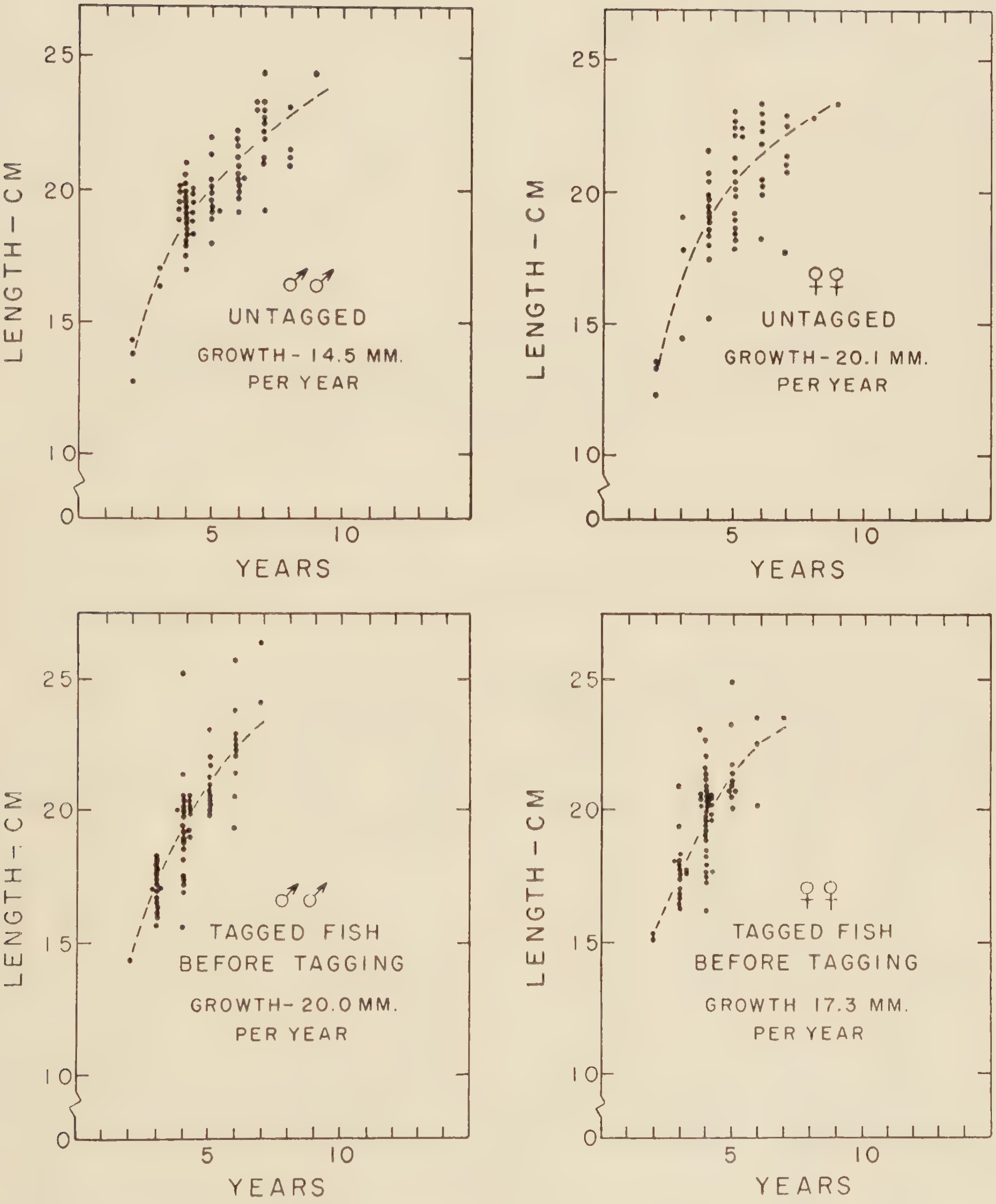


Figure 5. Growth-rates of untagged redfish and tagged redfish prior to the time of tagging. Based on otolith readings.

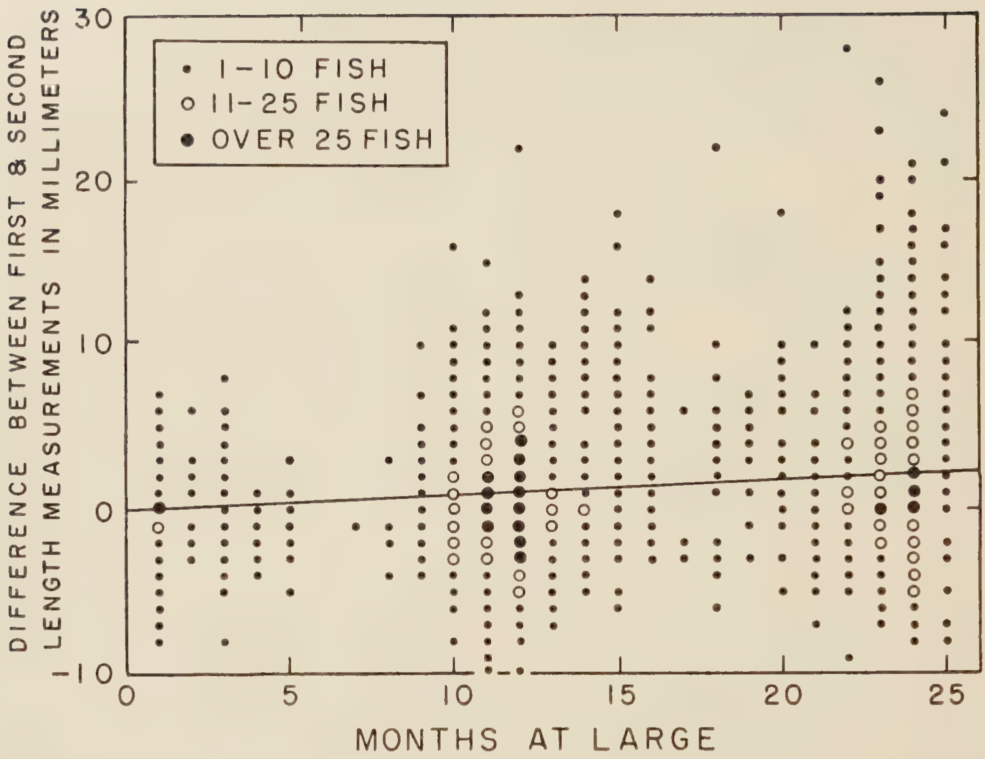


Figure 6. Regression line fitted to positive and negative growth increments of 2,365 recaptured fish (b = 0·08284).

Table 5

Length measurements of redfish recaptured four or more times

Length at tagging (mm)	1st Recapture		2nd Recapture		3rd Recapture		4th Recapture		5th Recapture		6th Recapture	
	Months at large	Length	Months at large	Length	Months at large	Length	Months at large	Length	Months at large	Length	Months at large	Length
157	11	156	21	155	23	157	23	156	–	–	–	–
160	11	160	21	159	22	160	23	160	–	–	–	–
161	11	157	21	168	22	168	23	168	–	–	–	–
165	10	166	13	163	22	165	23	165	–	–	–	–
169	12	171	15	172	24	170	25	172	–	–	–	–
175	13	176	14	179	21	179	23	184	–	–	–	–
176	11	173	12	173	21	174	23	175	–	–	–	–
188	1	183	10	190	12	189	24	196	–	–	–	–
193	12	192	12	191	22	192	23	193	–	–	–	–
195	10	202	12	204	16	209	25	205	–	–	–	–
195	13	195	20	196	25	200	25	200	–	–	–	–
198	2	200	12	203	13	202	22	202	23	205	–	–
198	10	202	15	205	23	205	24	200	–	–	–	–
198	11	203	12	202	23	201	24	202	–	–	–	–
202	2	202	13	202	24	203	25	203	–	–	–	–
202	12	205	13	200	24	203	25	200	–	–	–	–
202	11	203	12	204	13	202	16	205	24	207	–	–
203	12	205	13	204	16	208	24	210	–	–	–	–
205	1	203	11	205	12	203	24	205	–	–	–	–
209	2	206	11	209	12	215	16	213	–	–	–	–
213	1	210	3	214	12	221	15	229	–	–	–	–
223	12	220	13	225	23	222	24	223	–	–	–	–
228	12	220	15	225	23	222	25	221	–	–	–	–
251	1	248	12	244	21	248	24	250	–	–	–	–
252	12	252	15	252	19	256	24	255	25	255	–	–
254	1	256	11	258	12	254	22	263	23	254	24	256

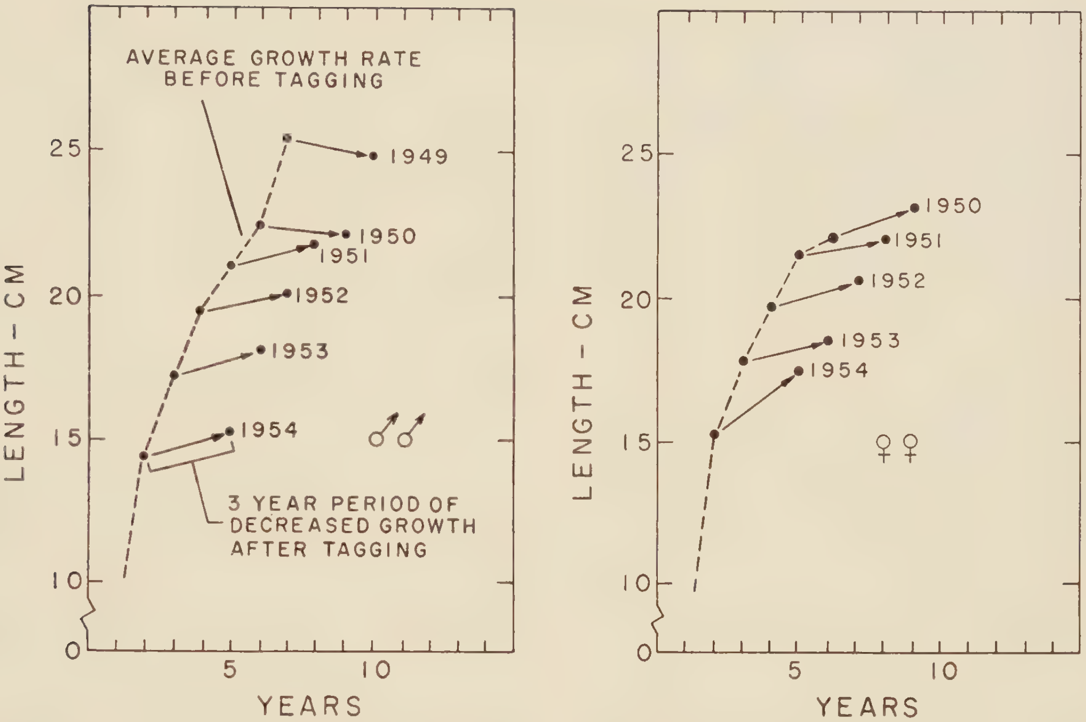


Figure 7. Apparent effect of tagging on growth-rate of separate year-classes during 3-year period of tagging.

Table 6

Numbers of different fish recaptured one or more times (Cumulative totals in parentheses)

Year	Number of fish tagged	Number of different fish recaptured	Total number of recaptures	Number of times recaptured through August 1958: 1	2	3	4	5	6
1956	3,385	1,525	(2,177)	1,041 (1,525)	349 (484)	109 (135)	20 (26)	5 (6)	1 (1)
1957	1,754	327	(383)	277 (327)	44 (50)	6 (6)	– –	– –	– –
1958	308	24	(25)	23 (24)	1 (1)	–	– –	– –	– –
Totals	5,447	1,876	(2,585)	1,341 (1,876)	394 (535)	115 (141)	20 (26)	5 (6)	1 (1)

Table 7

Total number of fish tagged with number and percentage recaptured through August 1958. Arranged by location of tagging and recapture to indicate degree of intermixing

Tagging locations	Total number of fish tagged	Total number of fish recaptured	% recaptured	Numbers and % recaptured at A	B	C	D
A – Steamer Dock	4,047	1,563	38·8	1,557 (38·6)	6 (0·2)	0	0
B – Wadsworth's Dock	562	70	12·5	2 (0·4)	68 (12·1)	0	0
C – Kinney's Mooring	505	223	44·2	223 (44·2)	0	0	0
D – Deep Cove	333	20	6·0	0	0	0	20 (6·0)

First, tagging had a visible effect on the growth pattern of the otoliths, suggesting that the physiology of the fish was definitely influenced by tagging. Second, the growth-rate obtained from otolith readings indicated that before tagging the tagged fish had grown at the same rate as untagged fish but that after tagging they grew more slowly. Finally, measurements of tagged fish show growth to be so slow that it is not in accord with the growth-rate of the untagged fish nor with the apparent growth-rate of the tagged fish in the years prior to tagging.

Migration

Redfish are found at Eastport throughout the year, and these studies indicate that they do not migrate away from the area. The number of fish observed or caught at the tagging site varied seasonally, however. This was probably caused by the response of the fish to seasonal changes in water temperature. Comparatively few fish were caught in the winter although considerable numbers were sometimes seen at the docks. As spring approached, greater numbers of both tagged and untagged fish appeared. Large numbers were usually present at night throughout summer and autumn. About 35 % of the tagged fish were recaptured at or near the tagging site (Table 1). There were no recaptures from any other location.

The repeated recapture of the same fish during a span of two years is perhaps the most remarkable aspect of the present study. Almost 400 fish were recaptured twice and one six times (Table 6). Such unexpected results in an open marine environment suggest that the fish are strongly attracted to particular home grounds.

Within the Eastport region, redfish showed little evidence of movement over distances of half a mile or less (Fig. 1 and Table 7). Fish tagged and released at locations A, B, and D were mainly recaptured at the same place. Each of these three locations was at the edge of deep water where redfish frequently appeared. A homing tendency was shown by fish removed from their home grounds, A, and released in a new location, C. Location C was a sheltered mooring in shallow water used only during bad weather. The movement from C to A of approximately two-thirds of a mile was the only clear example of concerted travel between areas. In this instance it was natural for the fish to seek deep water when released. This suggests that although the fish show little normal tendency to move, they will travel some distance when removed from their normal habitat.

The most unusual aspect of the local migration pattern was the comparative lack of intermixing of the two tagged groups between locations A and B. The two points are about 300 yards apart with no physical or hydrographic barriers between. The current sweeping along the shore can traverse the distance from B to A in less than 5 minutes. The situation would seem to dictate the complete mixing of the two groups. Despite these conditions, only 0·2 and 0·4 % respectively, of the A and B taggings have been recaptured at the adjoining location (Table 7). In July and August 1958, although 85 % of the fish caught at A were tagged, virtually none of the tagged fish were from location B.

Table 8

Population estimates based on numbers of tagged fish released and recaptured at Eastport

Date	Total number of fish captured	Total number of tagged fish available	Number of tagged fish recaptured	Estimated population
Sept. 1956	1,202	1,685	153	15,289
Nov. 1956	102	2,734	25	14,733
July 1957	644	2,803	270	9,573
Nov. 1957	335	3,676	162	7,955
June 1958	166	3,974	125	7,781
Aug. 1958	795	4,014	694	6,498

Population estimates

The behaviour of the Eastport redfish makes it difficult to estimate the size of the total population with a high degree of accuracy. The tendency for some of the fish to appear or to remain only at the steamer dock (location A, Fig. 1) results in an unusually large number of recaptures from a very small part of the total area of the harbour. The repeated recapture of a small number of the tagged fish introduces bias which gives a low estimate of the total number of fish. Estimates of the population at the steamer dock based on the procedures developed by Schnabel (1938) and Ricker (1948) range from 15,289 fish in September 1956 to the latest figure of 6,498 fish in August 1958 (Table 8). The authors' own observations would lead to the estimate that this population numbered at least 10,000 individuals, possibly more than 20,000.

Conclusions

Behaviour

The daily routine of Eastport redfish is influenced by the cycles of light intensity and tidal movement. The fish remain inactive on the bottom or in dark, rocky crevices during the day, becoming active at night. They feed mainly at night, moving toward the surface in search of food. Similar movements on the offshore grounds would cause a nocturnal reduction in redfish availability to the otter trawl, a condition that is typical of the commercial fishery in the Gulf of Maine.

Redfish generally appear to avoid swift currents and are very scarce at the docks as the "spring" tides of the monthly cycle begin. They respond seasonally to temperature, becoming inactive when the water cools below 40°F (4·4°C). Apparently the range from approximately 40° to 55°F (4·4°–12·8°C) is optimal for Eastport redfish.

Migration

The diurnal cycle of feeding results in a very local vertical migration within the area. Redfish will travel short distances when necessary, and they may be capable of homing to a chosen locality. There is no indication that they perform extensive migrations. Their sedentary behaviour suggests that long-distance travel, if undertaken, is a slow movement into new feeding grounds over a long period, rather than a cyclic movement to and from an area.

The Eastport population probably originated in the deep water of the Gulf of Maine, moving into the area through the deep channel north of Campobello Island. Living in the shallow water of the region, they are able to rise to the surface to feed on the abundant euphausiid shrimp. The apparent effect of living in the bright illumination near the surface has been to make the fish darker than the offshore group.

Growth

The normal growth-rate of Eastport redfish is slightly lower than that of the offshore Gulf of Maine fish. Growth of tagged fish is much slower than the normal growth of the Eastport fish. The lowered growth-rate appears to be due to some inhibiting influence of the tag.

Tagging has not validated the growth-rates obtained from previous Gulf of Maine studies. The annual length increment of tagged fish was only a fraction of the amount predicted in even the lowest computed growth-rate. Nonetheless, these results are suggestive evidence against the probability of fast growth within the Gulf of Maine redfish populations.

Acknowledgements

The success of tagging operations at Eastport was in part due to the co-operation of the local people. We are particularly indebted to Captain Oscar Kinney, Captain Karl Brooks, and Mr. Sheldon Trott, Jr., for their aid and the use of their equipment. We wish also to acknowledge the efforts of Messrs. Kenneth Allen, Claude F. Bocken, George M. Clarke, Franklin D. Roberts, and Walter T. Pereyra for their assistance.

References

Bigelow, H. B., & Schroeder, W. C., 1953. "Fishes of the Gulf of Maine." Fish. Bull. U.S., *53* (74): 577 pp.

Huntsman, A. G., 1922. "The fishes of the Bay of Fundy." Contr. Canad. Biol. for 1921, (3): 49–72.

Kelly, G. F., & Wolf, R. S., 1959. "Age and growth of the redfish (*Sebastes marinus*) in the Gulf of Maine." Fish. Bull. U.S., *60* (156).

Mavor, J. W., 1922. "The circulation of the water in the Bay of Fundy. Part 1. Introduction and drift bottle experiments." Contr. Canad. Biol., *1*: 103–24.

Ricker, W. E., 1948. "Methods of estimating vital statistics of fish populations." Indiana Univ. Publ., Sci. Ser., No. 15.

Schnabel, Z. E., 1938. "The estimation of the total fish population of a lake." Amer. Math. Mon., *45*: 348–52.

Schroeder, W. C., 1955. "Report on the results of exploratory otter-trawling along the continental shelf and slope between Nova Scotia and Virginia during the summers of 1952 and 1953." Deep-Sea Res., Suppl. vol. 3, Pap. Mar. Biol. Oceanogr.: 358–372.

Verrill, A. E., 1871. "On the food and habits of some of our marine fishes." Amer. Nat., *5*: 397–400.

Verrill, A. E., 1872. "Marine fauna of Eastport, Maine." Bull. Essex Inst., *3* (1): 2–6.

A/S L. Ihrich, Copenhagen

56

EXTRAIT

Rapp. et Proc.-Verb Vol. 150, 1961
Cons. Internat. Explor. de la Mer

9.

Vertical Distribution of Young Redfish in the Gulf of Maine

By

GEORGE F. KELLY and ALLAN M. BARKER

Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Introduction

Geographical distribution

Exploratory fishing by research and commercial vessels of several European and North American nations has extended our knowledge of distribution of redfish (*Sebastes marinus*) in all of the North Atlantic Ocean. This species is exploited by one country or another on virtually all deep-water banks from the Gulf of Maine in the south-west to the coast of Norway and the Barents Sea banks in the east. Although adult redfish are found primarily as bottom dwellers on the slopes of the continental shelf, diurnal variations in availability in some areas suggest that they sometimes rise above the bottom an undetermined distance. There is strong evidence that some adult redfish live pelagically at intermediate depths over certain areas of the deep ocean. The possibility that these may represent a very large pelagic population inhabiting vast areas of the ocean is perhaps the most important distributional question of the moment.

The existence of a pelagic population of adult redfish over deep water was first proposed by Nansen (1886). He found fresh specimens of redfish in the stomachs of hooded seals caught in the middle of the Arctic Ocean over depths of 1,500 fms. The redfish could only have been captured near the surface. Hjort (1900) confirmed Nansen's theory by catching considerable numbers of redfish on floating lines set at 100–200 m over very deep water in many parts of the Norwegian Sea. More recently the presence of great numbers of larvae at the surface hundreds of miles from the nearest known bottom-dwelling redfish stock suggests that the larvae originated from a pelagic population. However, there have been no collections of pelagic adults in these areas to substantiate the existence of a large midwater population. Evidence is needed from experimental midwater fishing to establish the size and distribution of such a population.

The pelagic larvae of *Sebastes* have been collected at many locations across the North Atlantic, but little is known of the duration of the pelagic period and the rate of growth, habits and distribution of young redfish during that time. The early life history is important in considering the definition of redfish stocks, since the distance of larval transport by water currents can affect profoundly the degree of intermingling of progeny from geographically separated stocks. The depth at which females release the living larvae and the relationship of these larvae to bottom-dwelling stocks is not known. Newly-spawned larvae (5 to 6 mm) first appear at the surface in late spring. Specimens ranging between 5 and 20 mm have been frequently collected during the summer in the upper 10 to 20 m of water in many areas. Beyond this size the young fish become less available to sampling gear until they again appear on the bottom in early autumn at a length of about 50 mm. Estimates by various investigators of the length of the pelagic period, based on these data, have ranged from a few months to more than a year. None of the estimates was supported by direct evidence from a series of length measurements of collected specimens. The comparative scarcity of young between 20 and 50 mm in earlier collections left a gap that could only be satisfactorily bridged through the investigation of the natural history of fish of that size.

Review of earlier larval studies

In the eastern Atlantic, *Sebastes* larvae were collected from the waters west and south of Iceland by Schmidt (1904) and Jensen (1922). Schmidt found large numbers of larvae in Denmark Strait during May and June 1903. Jensen found them similarly abundant in the same general area five years later. He recorded adult redfish as being widely distributed along the west coast of Greenland and in Davis Strait, but he concluded that this species does not breed in that area. No *Sebastes* larvae were taken in his plankton collections during spring and summer. It was not until late September that small fish (27–43 mm) appeared. He considered these to be the young spawned in the Denmark Strait which had drifted with the current around Cape Farewell to the south-west coast of Greenland. The distance traversed would be more than 500 miles.

Some years later Jensen (1926) altered his hypothesis of larval drift when he found young redfish along the west coast of Greenland. The specimens were sufficiently plentiful and of the proper size (7–17 mm) to have been spawned close by the collecting stations. While this new information removed the need for the hypothesis of extended larval drift to explain the presence of redfish in the Davis Strait region in 1925, it did not invalidate Jensen's original hypothesis that such an extended larval drift had indeed occurred in 1908–09.

Tåning (1949) summarized the extensive collections of the R/V "Dana" and reviewed the earlier studies in the light of his own findings. He agreed that Jensen's theory of larval drift to West Greenland was probably correct for certain periods of years, but he was not satisfied that larval drift alone could explain the occurrence of tremendous numbers of larvae over deep water at long distances from the nearest fishing banks. He felt that the presence of suitable hydrographic conditions over a wide area suggested the existence of a "pelagic high boreal community" of adult redfish distributed at mid-depths over the deep water nearby where larvae were found. Tåning was convinced that the pelagic population was of tremendous size and could eventually support a substantial commercial fishery.

In the western Atlantic, redfish larvae have been taken virtually everywhere that adults occur. Bigelow (1914 and 1917) reported larval redfish to be the most commonly recurrent fish species in the Gulf of Maine plankton in the summers of 1912–1915. They were usually found between the coast and the 200 m contour. Dannevig (1919) found redfish larvae to be numerous in the Gulf of St. Lawrence and on the Nova Scotian banks during 1914–1915, mainly along the edges of banks adjacent to deep water. Frost (1938) reported redfish larvae at many stations in the Gulf of St. Lawrence and around Newfoundland in spring and autumn during 1931 to 1935. Steele (1957) recorded the presence of larvae along the Gaspé coast in the Gulf of St. Lawrence.

The point that seems to characterize the findings of eastern Atlantic studies is that large numbers of larvae appear to be concentrated at the surface in some areas where adult *Sebastes* are not known to occur. Conversely, in some years no larvae are collected in regions where large redfish are abundant. On the other hand, in no instance have western Atlantic studies shown larvae to be present where adult redfish do not occur. If these differences are real, it is not possible to say whether they result from different spawning behaviour of adults in the two areas, or are, perhaps, the result of fundamentally different hydrographic systems influencing larval distribution.

In earlier studies on both sides of the Atlantic, the emphasis was on numbers of larvae encountered, with little regard for specific depth of the catch or sizes of larvae collected. Many collections were from vertical or oblique hauls taken from a specified depth to the surface.

There are relatively few records of redfish greater than 20 mm in length that were collected in plankton nets. Jensen (1926) listed several specimens ranging as large as 49 mm taken in his ring-trawls, but the bulk of his collections were of larvae smaller than 20 mm. Tåning (1949) mentions an upper limit of 21 mm, in citing the size range of almost 1,100 larvae taken in a single haul of the 2 m stramin net. Dannevig (1919) illustrates redfish larvae ranging from a 5·6 mm larva to a 20 mm postlarva, citing only the mid-length of each station collection in the text. Although Frost (1938) did not list sizes, her data from collections of the R/V "Cape Agulhas" were summarized in a table by Perlmutter and Clarke (1949). Of more than 600 specimens in her collections, only three exceeded 20 mm, the largest being 37 mm. Bigelow (1914 and 1917) cites five stations where the size range exceeded 20 mm, but the number of specimens of greater size is not stated. He described the concentration of larvae at one station as a "swarm" ranging from 14 to 40 mm. This probably contained many fish larger than 20 mm.

There was no specifically directed effort to examine the vertical distribution of the larvae in any of the studies cited. Perhaps it was presumed by earlier workers that once the fish reached 20 mm they quickly settled to the bottom wherever they chanced to be. Experience while bottom trawling in the Gulf of Maine (Kelly and Wolf, 1959) reveals the youngest age-group (pre-annulus) ranging between 35 and 55 mm and averaging 48 mm in length in November. A comparison of the size range sampled by plankton nets and taken in the bottom trawls suggests that larger postlarvae have been virtually unsampled in most previous studies. Special studies of factors affecting the 20 to 60 mm young seemed necessary before theories of larval drift could be considered in proper perspective. With this purpose in mind, a programme of midwater trawling was planned for the Gulf of Maine in 1957 and 1958.

Objectives

The purpose of the study was to test the effectiveness of the midwater trawl for sampling young redfish in late summer, to determine their pelagic distribution, abundance and growth-rate during the pelagic period. Specific objectives were to:

(1) determine the horizontal and vertical distribution of young redfish with respect to water temperature;

(2) measure relative abundance of young redfish;

(3) examine diurnal variations in depth distribution and abundance of young;

(4) determine growth-rate of young from changes in size composition during the pelagic stage, to validate the computed age at first year-zone formation in scales and otoliths;

(5) estimate the duration of the pelagic period.

Methods

Study area

This paper is the result of field work done on four cruises of the R/V "Albatross III" in late July and early September of 1957 and 1958. In 1957 a series of midwater stations were sampled in the south-western part of the Gulf of Maine, an area where a fairly large brood-stock of redfish was known to exist (Fig. 1). The station locations were selected, using the records of Bigelow's early catches as a starting point, allowing freedom for exploratory fishing in areas that appeared promising (Table 1). On the basis of the success of the 1957 sampling, the 1958 programme duplicated the sampling as a check on the relative strength of the new year-class (Table 2).

Description of fishing gear

The 10 ft Isaacs-Kidd midwater trawl was used as the sampling gear because it is well suited for the high-speed collection of small fish (Isaacs and Kidd, 1953). The outstanding feature of this trawl is that no towing cables cross in front of the mouth of the net to frighten or interfere with animals in its path. The trawl was rigged with a Leavitt (1935) net-releasing device operating as an opening-and-closing net to minimize the contamination of collections while setting and retrieving the gear. The entire net was lined with $^3/_8$ inch (stretched mesh) cotton netting capable of retaining redfish as small as 10 mm.

A cod-end with $^3/_8$ inch mesh was used on all cruises except No. 117 in September 1958. At that time the fish taken in the first few tows were fewer and much smaller than those caught at the same time the previous year. A cod-end consisting of stramin netting was added to retain any smaller fish that might escape. This mesh retains fish as small as the new-born 5 mm redfish larvae.

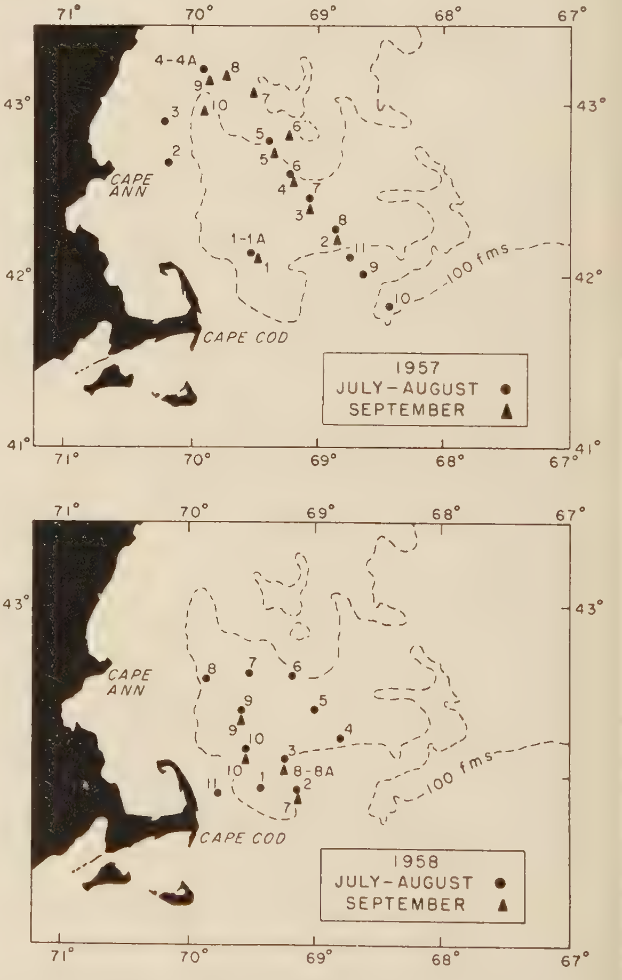


Figure 1. Redfish midwater trawl stations occupied in the Gulf of Maine in 1957 and 1958. (For clarity the cruise numbers have been omitted from the figure – see Tables 1 and 2 for complete station designation.)

Depth calibration of the gear

At the outset of operations the net was run through a series of calibration tows, to determine the relationship of the length of trawl warp to depth of net in the water. A telemetric depth recorder (Boden, *et al.*, 1955) was used for calibration.

The trawl was towed at a series of ten depths from the surface to 150 m. Depth was checked on the tele-

Table 1

Summary of 1957 collections. The number of redfish and number of midwater trawl tows are listed by depth for each station

(Number of tows in parentheses)

“Albatross III” – Cruise Number 99

Station Number	Lat. N	Long. W	Date of collection 1957	Depth (m)	Surface water temperature	
					°F	°C
99–1	42°08′	69°30′	July 26–27	233–264	66·2	19·0
99–1A	42°08′	69°30′	Aug. 1	233–264	–	–
99–2	42°43′	70°10′	July 28	123–143	63·6	17·6
99–3	42°55′	70°13′	July 28	141–187	65·4	18·6
99–4	43°12′	69°55′	July 29	163–176	–	–
99–4A	43°09′	69°48′	July 30	220	67·4	19·6
99–5	42°47′	69°21′	July 30	224–246	66·3	19·1
99–6	42°35′	69°11′	July 30	268–290	66·2	19·0
99–7	42°37′	69°04′	July 31	257–299	66·0	18·9
99–8	42°15′	68°51′	July 31	268	66·0	18·9
99–9	42°01′	68°38′	July 31	207	66·7	19·3
99–10	42°49′	68°25′	July 31	246	–	–
99–11	42°10′	68°45′	July 31– Aug. 1	231–251	66·6	19·2

“Albatross III” – Cruise Number 102

Station Number	Lat. N	Long. W	Date of collection 1957	Depth (m)	°F	°C
102–1	42°08′	69°30′	Sept. 5–6	233–264	64·6	18·1
102–2	42°15′	68°51′	Sept. 6	268	65·0	18·3
102–3	42°27′	69°04′	Sept. 6–7	257–299	64·8	18·2
102–4	42°35′	69°11′	Sept. 7	268–290	–	–
102–5	42°44′	69°19′	Sept. 7–8	231–275	–	–
102–6	42°49′	69°15′	Sept. 8	198	–	–
102–7	43°06′	69°33′	Sept. 9	176–180	60·0	15·5
102–9	43°09′	69°52′	Sept. 9	198	60·2	15·6
102–10	42°57′	69°55′	Sept. 9	198	–	–

“Albatross III” – Cruise Number 99 – July–August

Station Number	Depth in metres									
	Surface	10	20	30	40	60	80	100	110	Total
99–1	–	6(3)	440(3)	21(4)	7(3)	24(3)	–	1(2)	–	499(18)
99–1A	–	49(2)	58(2)	36(1)	–	–	–	–	–	143(5)
99–2	–	3(2)	2(2)	0(2)	0(2)	–	–	–	–	5(8)
99–3	0(1)	0(2)	3(2)	0(2)	1(2)	0(1)	–	–	–	4(10)
99–4	0(1)	25(2)	49(2)	0(1)	1(1)	0(1)	–	–	–	75(8)
99–4A	–	–	1(1)	–	–	–	–	–	–	1(1)
99–5	–	1(2)	7(2)	9(2)	2(2)	–	–	–	–	19(8)
99–6	–	82(1)	1990(1)	–	–	–	–	–	–	2072(2)
99–7	–	–	582(1)	–	–	–	–	–	–	582(1)
99–8	–	–	560(1)	–	–	–	–	–	–	560(1)
99–9	–	–	31(1)	–	–	–	–	–	–	31(1)
99–10	–	0(1)	0(1)	0(1)	0(1)	–	–	–	–	0(4)
99–11	–	113(2)	138(2)	30(2)	12(2)	6(1)	–	–	–	299(9)
Total	0(2)	279(17)	3861(21)	96(15)	23(13)	30(6)	–	1(2)	–	4290(76)

“Albatross III” – Cruise Number 102 – September

Station Number	Surface	10	20	30	40	60	80	100	110	Total
102–1	–	9(2)	6(2)	5(2)	9(2)	–	–	–	–	29(8)
102–2	–	4(1)	0(1)	0(1)	0(1)	–	–	–	–	4(4)
102–3	–	8(2)	6(2)	1(2)	45(2)	16(1)	29(2)	282(2)	177(1)	564(14)
102–4	–	0(1)	14(1)	1(1)	2(1)	–	0(1)	0(1)	1(1)	18(7)
102–5	–	88(2)	51(2)	17(1)	2(1)	4(1)	387(1)	220(1)	0(1)	769(10)
102–6	–	4(1)	0(1)	–	0(1)	–	–	12(1)	–	16(4)
102–7	–	5(1)	0(1)	–	0(1)	–	0(1)	0(1)	–	5(5)
102–9	–	0(1)	0(1)	–	–	–	–	1(1)	–	1(3)
102–10	–	3(1)	6(1)	–	0(1)	0(1)	14(1)	9(1)	–	32(6)
Total	–	121(12)	83(12)	24(7)	58(10)	20(3)	430(6)	524(8)	178(3)	1438(61)

Table 2

Summary of 1958 collections. The number of redfish and number of midwater trawl tows are listed by depth for each station

(Number of tows in parentheses)

"Albatross III" – Cruise Number 116

Station Number	Lat. N.	Long. W	Date of collection 1958	Depth (m)	Surface water temperature °F	°C
116–1	41°55′	69°30′	July 28–29	238–255	63·7	17·6
116–2	41°56′	69°12′	July 29	260–275	64·3	17·9
116–3	42°07′	69°12′	July 29–30	238–245	64·9	18·3
116–4	42°15′	68°51′	July 30	268	64·4	18·0
116–5	42°27′	69°04′	July 30	257–299	64·1	17·8
116–6	42°35′	69°11′	July 30	268–290	64·5	18·1
116–7	42°33′	69°31′	July 31	330–339	64·9	18·3
116–8	42°32′	69°48′	July 31	282–304	62·6	17·0
116–9	42°21′	69°36′	July 31	282–315	64·9	18·3
116–10	42°09′	69°35′	July 31– Aug. 1	273–304	65·1	18·4
116–11	41°52′	69°48′	Aug. 1	158	–	–
"Albatross III" – Cruise Number 117						
117–7	41°56′	69°12′	Sept. 14	260–275	61·5	16·4
117–8	42°07′	69°12′	Sept. 14	238–245	60·6	15·9
117–8A	42°07′	69°12′	Sept. 15–16	238–246	60·6	15·9
117–9	42°21′	69°36′	Sept. 15	282–315	61·4	16·3
117–10	42°09′	69°35′	Sept. 15	273–304	61·0	16·1

"Albatross III" – Cruise Number 116 – July–August

Station Number	Depth in metres									
	Surface	10	20	30	40	60	80	100	110	Total
116–1	–	0(2)	0(1)	0(1)	0(1)	0(1)	0(1)	–	–	0(7)
116–2	–	1(1)	1(1)	0(1)	0(1)	0(1)	0(1)	–	–	2(6)
116–3	–	1(1)	1(1)	0(1)	0(1)	0(1)	–	–	–	2(5)
116–4	–	2(1)	3(1)	–	0(1)	–	–	–	–	5(3)
116–5	–	11(1)	1(1)	0(1)	0(1)	0(1)	0(1)	–	–	12(6)
116–6	–	1(1)	1(1)	0(1)	0(1)	–	–	–	–	2(4)
116–7	0(1)	0(1)	0(1)	0(1)	–	–	–	–	–	0(4)
116–8	–	0(1)	1(1)	0(1)	–	–	–	–	–	1(3)
116–9	–	17(2)	22(2)	0(1)	–	–	–	–	–	39(5)
116–10	–	0(1)	1(1)	0(1)	0(1)	–	–	–	–	1(4)
116–11	–	6(1)	8(1)	–	–	–	–	–	–	14(2)
Total	0(1)	39(13)	39(12)	0(9)	0(7)	0(4)	0(3)	–	–	78(49)
"Albatross III" – Cruise Number 117 – September										
117–7	–	12(1)	4(1)	4(1)	1(1)	0(1)	0(1)	–	–	21(6)
117–8	–	10(1)	–	–	–	–	–	–	–	10(1)
117–8A	–	146(1)	31(1)	7(1)	6(1)	–	0(1)	–	–	190(5)
117–9	–	36(1)	0(1)	1(1)	0(1)	–	1(1)	–	–	38(5)
117–10	–	2(1)	0(1)	0(1)	–	1(1)	0(1)	–	–	3(5)
Total	–	206(5)	35(4)	12(4)	7(3)	1(2)	1(4)	–	–	262(22)

metric recorder and the amount of trawl warp passing over a metered wheel was recorded at each depth. This was done at about 4½ knots vessel speed. A curve was drawn to the points, and standard trawl warp lengths were taken from the curve for 10 metre intervals from the surface to 110 m. In all subsequent operations the trawl was set by paying out on the metered wheel the standard trawl warp length required for a desired depth, after which speed, measured by engine RPM's, was kept constant.

Station procedure

At each station, a series of 1 hr tows was made at 10, 20, 30, and 40 m. If large numbers of redfish were found, the entire series was repeated a second or third time to determine whether diurnal variations occur in the vertical distribution of the larvae. Occasionally the series was extended to 60, 80, 100, and 110 metres.

The net was set to the desired depth in the closed position, opened with the first messenger, and towed for one hour. The second messenger closed the net and it was then retrieved. The number of tows made at the various depths on each cruise is shown in Tables 1 and 2. Fishing effort was not evenly distributed among the depths on any of the cruises. A standard bathythermograph cast was made at each station.

Results

Abundance

The number of larvae collected in 1957 was almost twenty times greater than in 1958 (Tables 1 and 2). Catch-per-tow by depth shows the highest relative abundance of young fish at 20 m in July–August and at 80–100 m in September 1957 (Table 3). In 1958 the small numbers taken were mainly in the 10–30 m zone. Admittedly, the high and low relative abundances of the 1957 and 1958 year-classes afford no basis for quantitative evaluation of average relative abundance of young-of-the-year redfish. However, judged from previous experience in sampling young redfish in the same area with plankton nets and small-mesh otter trawls, the large numbers of young available in 1957 suggest that larval survival in that year was above average, and that 1958 survival was below average.

Observed water temperatures were similar during the two years. Minor differences were detected, but it appears unlikely that these could cause such great variation in the success of spawning or of larval survival. The apparent failure of the 1958 year-class seems more likely the result of other causes.

Distribution

In July–August 1957 most of the redfish were found in the area south of Cape Ann (Fig. 1). A month later the greatest numbers were still in this region, but they appeared to be concentrated along the easterly side of the deep water (stations 102–103 and 102–105). In 1958, the sampling was confined to the southern area, and, although the fish were scarce, in July–August the largest numbers of larvae were taken in the same general area as in 1957.

The 1957 samples indicated that a significant change in depth distribution had occurred between July–August and September. About 98 % of the fish were caught between 10 and 30 m in July–August (Table 1). In September, the fish were taken deeper and 80 % of the catch was from depths of 80 to 110 metres.

The 1958 data are generally similar in that July–August larvae were found at 10 and 20 metres, while the September distribution included a few specimens as deep as 80 m (Table 2). However, 1958 does not show the spectacular change in vertical distribution of larvae that was observed in 1957.

The vertical distribution of larvae with respect to water temperature showed some interesting differences. In July–August 1957, all of the large catches were taken within the thermocline (Fig. 2). It is surprising that the larvae should remain in this area of high temperature gradient where it would appear that they might be exposed to changes of 6° to 15°F. Perhaps their position in the thermocline is advantageous since it enables them to select a preferred temperature with a minimum of vertical movement in the water column.

In September 1957, most of the fish were found in cool water well below the thermocline. This water was almost isothermal from a point just below the thermocline to the bottom.

Table 3

Summary of fishing effort and mean catch per tow, by depth, 1957—1958

Depth (m)	July–August 1957			September 1957			July–August 1958			September 1958		
	Number of		Catch	Number of		Catch	Number of		Catch	Number of		Catch
	tows	fish	per tow	tows	fish	per tow	tows	fish	per tow	tows	fish	per tow
Surface	2	0	0·0	–	–	–	1	0	0·0	–	–	–
10	17	279	16·4	12	121	10·0	13	39	3·0	5	206	41·2
20	21	3861	183·8	12	83	6·9	12	39	3·3	4	35	8·8
30	15	96	6·5	7	24	3·4	9	0	0·0	4	12	3·0
40	13	23	1·8	10	58	5·8	7	0	0·0	3	7	2·3
60	6	30	5·0	3	20	6·7	4	0	0·0	2	1	0·5
80	–	–	–	6	430	71·7	3	0	0·0	4	1	0·3
100	2	1	0·5	8	524	65·5	–	–	–	–	–	–
110	–	–	–	3	178	59.3	–	–	–	–	–	–
Total	76	4,290		61	1,438		49	78		22	262	
Mean catch per tow			56·4			23·6			1·6			11·9

Table 4

Summary of numbers of redfish by depth and hour of day captured (Eastern Daylight Time)

Cruise Number 99 – July–August 1957

Depth in			Hours				Sunrise			Hours		
metres	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
10	0	–	–	–	97	–	1	–	3	23	3	0
20	583	–	0	–	560	49	–	31	0	–	2	347
30	13	–	0	–	0	–	–	21	–	–	0	0
40	–	9	1	–	1	–	0	–	–	3	–	0
60	–	–	–	6	22	0	–	–	–	–	–	–
100	–	–	–	–	–	–	–	–	–	–	–	–
Total	596	9	1	6	680	49	1	52	3	26	5	347

Depth in			Hours						Sunset				
metres	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	Total
10	–	–	49	0	–	–	–	16	87	–	–	–	279
20	0	–	–	–	7	22	–	–	36	145	2079	–	3861
30	0	17	0	–	–	9	36	–	–	–	–	–	96
40	–	0	0	6	–	1	2	0	–	–	–	–	23
60	–	–	–	–	2	–	–	0	–	–	–	–	30
100	–	–	–	–	–	1	0	–	–	–	–	–	1
Total	0	17	49	6	9	33	38	16	123	145	2079	–	4290

Cruise Number 102 – September 1957

Depth in			Hours				Sunrise				Hours	
metres	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
10	8	–	5	–	0	–	5	–	–	–	4	–
20	3	1	–	0	–	3	–	11	–	–	–	14
30	–	2	–	0	–	–	3	–	–	–	–	–
40	–	0	–	9	18	0	–	–	–	–	–	–
60	4	–	0	–	–	16	–	–	–	–	–	–
80	–	–	387	14	–	–	–	0	–	–	–	–
100	12	–	–	220	9	–	0	–	0	–	–	–
110	–	–	–	–	0	–	–	–	–	–	–	–
Total	27	3	392	243	27	19	8	11	0	–	4	14

Depth in				Hours					Sunset				
metres	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	Total
10	–	–	–	–	0	0	–	–	87	–	3	9	121
20	–	–	–	–	–	5	0	–	–	40	–	6	83
30	1	–	–	–	–	–	1	–	–	–	17	–	24
40	–	2	–	–	–	–	–	27	–	–	0	2	58
60	–	–	–	–	–	–	–	–	–	–	–	–	20
80	–	–	–	0	–	–	–	–	–	–	29	–	430
100	–	–	–	–	0	–	–	1	–	282	–	–	524
110	–	–	–	–	–	1	–	–	–	–	–	177	178
Total	1	2	–	0	0	6	1	28	87	322	49	194	1438

The temperature profiles taken at stations yielding large and small catches of young fish were generally similar each month in 1957 (Fig. 2). In July–August 1957, the areas of larval abundance showed less clearly defined thermoclines. However, it would be difficult to determine if the larvae seek a lower temperature gradient, or whether the currents that serve to concentrate the larvae also function to disperse the thermocline and reduce the temperature gradient. Despite variations of a few degrees in surface temperature, the range of temperatures in the thermocline was similar, and the temperature of the deep isothermal water was nearly the same in both years.

Diurnal variations

Diurnal variations in numbers of fish were evident in the 1957 samples (Table 4). Eighty-seven per cent. of the total number of fish caught in July–August 1957 were taken between twilight (1800) and daybreak (0600). In September 1957, 96 % of the larvae were

Table 5
Summary of fishing effort and mean catch per tow by time of day (Eastern Daylight Time)

	Time of day	Total number of tows	Number of tows with redfish	Number of redfish	Mean catch per tow
1957 July–August Cruise No. 99	0600–1200	17	11	434	25·5
	1200–1800	25	9	114	4·6
	1800–0000	14	12	2401	171·5
	0000–0600	20	12	1341	67·0
Total		76	44	4290	56·4
September Cruise No. 102	0600–1200	12	7	37	3·1
	1200–1800	10	3	9	0·9
	1800–0000	16	12	681	42·6
	0000–0600	23	16	711	30·9
Total		61	38	1438	23·6
1958 July–August Cruise No. 116	0600–1200	13	6	28	2·2
	1200–1800	9	3	40	4·4
	1800–0000	12	4	4	0·3
	0000–0600	15	3	6	0·4
Total		49	16	78	1·6
September Cruise No. 117	0600–1200	7	5	22	3·1
	1200–1800	8	4	14	1·8
	1800–0000	4	2	184	46·0
	0000–0600	3	2	42	14·0
Total		22	13	262	11·9

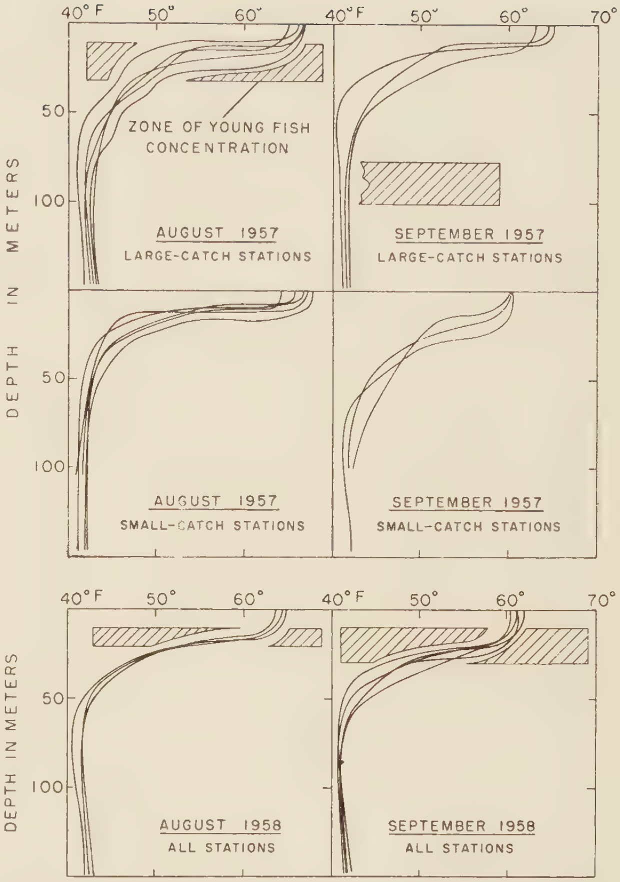


Figure 2. Water temperature profiles recorded at redfish mid-water trawl stations in the Gulf of Maine in 1957 and 1958.

caught at night. With the exception of one large catch at 1100 hours in July–August, all of the largest catches of larvae at all depths were made during the night. This suggests that young fish are less available to the trawl during the day-time, perhaps being able to see it in time to escape.

The catch-per-tow of larvae collected on the four cruises is summarized in Table 5, arranged by the quarter of the day when caught. In general, the results show a higher percentage of night-time tows containing redfish, and a higher average catch-per-tow at night than in the day-time. The July–August 1958 data are not consistent with the rest, but these contain the least number of redfish and are therefore less conclusive than the other data. It appears that midwater trawling at night is many times more effective than day-time trawling, with the afternoon period being the least likely to produce large catches.

Day and night fishing was undertaken at several stations in an attempt to show a diurnal pattern of vertical movement by young fish. Despite this intensive effort, the tows that netted fish are too dispersed through the depths to show any clear pattern of diurnal vertical movement. In July–August 1957, the largest catches were consistently in the 10 to 30 m depths, day and night. In September 1957, the concentrations of small fish were at 80 to 110 m at night. The only suggestion of diurnal variation on both occasions was a slight vertical movement within the relatively narrow range of depths where the fish were concentrated at the time. There was no indication of diurnal movement of young fish between surface and deep water.

On two occasions in 1957 single large redfish were taken at mid-depth under circumstances suggesting either that they were living pelagically or were involved in a nocturnal vertical migration. Each was caught during early morning darkness, between 0230 and 0400 hours, a 29 cm female at 60 m depth in August and a 20 cm male at 100 m in September. The female was gravid with young about to be released and may have been rising in the water to release the young near the surface. Whatever the purpose, these occurrences at

Table 6

Summary of redfish length-frequencies by depth, July—August 1957 ("Albatross III"— Cruise Number 99)

Length (mm)	Depth in metres 10	20	30	40	60	100	Total
5	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–
8	–	1	–	–	–	–	1
9	–	1	–	–	–	–	1
10	1	3	–	–	–	–	4
11	2	7	1	–	–	–	10
12	6	23	2	–	–	–	31
13	10	28	7	1	–	–	46
14	25	58	13	1	–	–	97
15	22	74	12	–	–	–	108
16	12	105	8	1	1	–	127
17	19	127	8	–	–	–	154
18	19	153	3	–	1	–	176
19	13	225	7	2	1	–	248
20	8	237	5	4	–	–	254
21	8	287	4	–	1	–	300
22	12	343	2	3	2	–	362
23	12	349	3	1	2	–	367
24	14	346	3	–	–	1	364
25	10	330	4	2	2	–	348
26	7	240	2	–	2	–	251
27	11	241	1	1	3	–	257
28	10	187	3	1	7	–	208
29	13	149	3	1	–	–	166
30	12	90	1	3	3	–	109
31	11	84	–	–	–	–	95
32	6	59	2	1	3	–	71
33	6	36	–	–	–	–	42
34	3	32	2	1	–	–	38
35	2	21	–	–	1	–	24
36	3	14	–	–	1	–	18
37	2	4	–	–	–	–	6
38	–	7	–	–	–	–	7
39	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–
Total	279	3861	96	23	30	1	4290
Mean length (mm)	22·2	23·8	19·5	24·1	27·2	23·5	23·6

mid-depth support the hypothesis that movement off the bottom is the cause of a nocturnal decrease in availability of redfish in the Gulf of Maine.

Length composition

Redfish taken at the southern stations in July–August 1957 were considerably larger than those from northern stations. North of Cape Ann (Fig. 1) the fish were from 4 to 10 mm smaller and were fewer than at the stations to the south. This condition was altered somewhat in September 1957, and the larger fish were found more northerly along the eastern edge of the deep water. The numbers of larvae taken in the 1958 collections are not sufficient for a comparison of length composition.

The length composition by depth in 1957 indicates a slight trend toward larger fish in deep water. The size range from surface to bottom is surprisingly uniform both in July–August and September (Tables 6 and 7, Figure 3). Apart from individual differences between stations, the average lengths of larvae from each depth are within a few millimetres. In both months the smallest average length was observed at the 30 m depth. There is no apparent explanation for this.

In July–August 1958, the fish were concentrated in

Table 7

Summary of redfish length-frequencies by depth, September 1957 ("Albatross III" — Cruise Number 102)

Length (mm)	Depth in metres 10	20	30	40	60	80	100	110	Total
15	–	–	–	–	–	–	–	–	–
16	–	–		–	–	–	–	–	–
17	–	–	–	–	–	–	1	–	1
18	–	–	1	–	–	1	–	–	2
19	–	–	–	–	–	–	–	–	–
20	–	1	–	–	–	1	–	–	2
21	–	–	1	–	–	1	–	–	2
22	–	1	–	–	–	–	–	–	1
23	2	–	–	–	–	1	–	–	3
24	1	1	–	–	1	2	–	–	5
25	1	2	–	1	–	–	1	–	5
26	2	3	–	–	–	2	1	1	9
27	–	1	1	–	–	5	2	–	9
28	2	3	–	1	1	2	2	–	11
29	–	4	–	–	1	4	3	1	13
30	5	3	1	–	–	5	5	1	20
31	3	2	1	5	1	5	11	3	31
32	2	2	–	5	–	14	21	4	48
33	7	5	2	3	1	13	26	6	63
34	3	2	2	6	–	22	42	14	91
35	11	10	2	6	2	26	59	25	141
36	13	8	6	3	1	22	72	25	150
37	14	10	2	5	–	37	62	27	157
38	9	2	2	6	1	26	40	26	112
39	13	5	–	8	2	33	35	16	112
40	6	2	1	4	3	27	23	13	79
41	5	4	1	–	1	19	20	8	58
42	6	2	–	1	1	21	17	3	51
43	4	4	–	1	–	24	19	2	54
44	3	1	–	2	1	20	13	2	42
45	2	–	–	1	1	15	7	–	26
46	1	–	–	–	–	10	4	1	16
47	–	1	1	–	–	11	6	–	19
48	3	–	–	–	–	6	9	–	18
49	–	1	–	–	–	11	6	–	18
50	1	2	–	–	2	8	5	–	18
51	–	1	–	–	–	10	7	–	18
52	–	–	–	–	–	8	2	–	10
53	–	–	–	–	–	3	–	–	3
54	1	–	–	–	–	7	2	–	10
55	1	–	–	–	–	4	1	–	6
56	–	–	–	–	–	2	–	–	2
57	–	–	–	–	–	1	–	–	1
58	–	–	–	–	–	1	–	–	1
59	–	–	–	–	–	–	–	–	–
60	–	–	–	–	–	–	–	–	–
Total	121	83	24	58	20	430	524	178	1438
Mean length (mm)	37·7	36·0	34·9	36·6	38·4	40·5	38·2	37·4	38·5

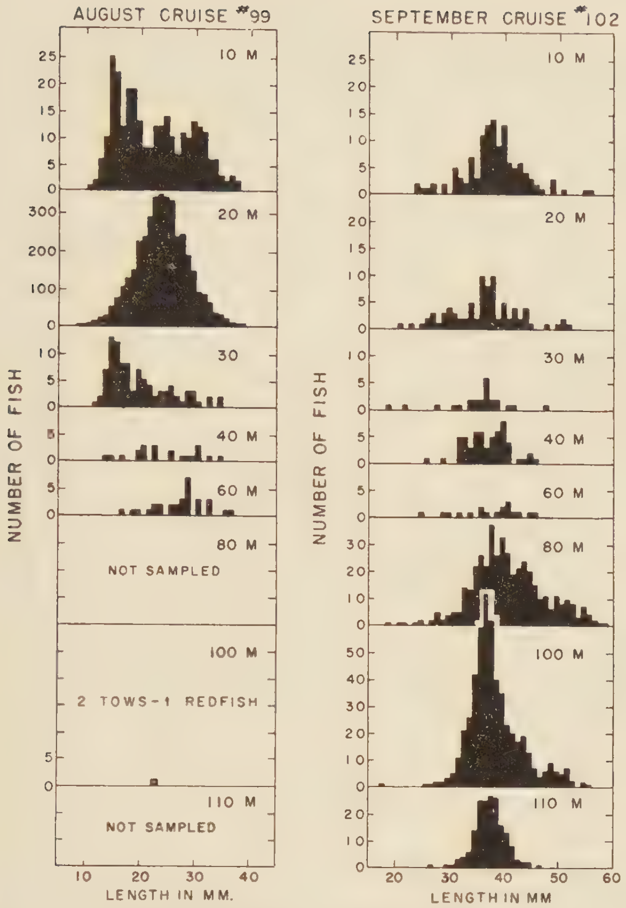


Figure 3. Length composition and depth distribution of young redfish taken by midwater trawl in 1957.

the upper strata, with equal numbers at 10 and 20 m (Table 8 and Figure 4). Size ranges at the two depths were similar. In September there was a gradual increase in average length associated with increased depth (Table 9 and Figure 4). The large numbers of small larvae at 10 m depth and the generally smaller average lengths at all depths can be attributed to the added stramin cod-end.

In comparing the length composition of the specimens collected during the two years, the similarity of the July–August data and the dissimilarity of the September collections are evident. The average lengths recorded in July–August of both years are nearly identical despite the tremendous difference in the number of fish collected (Tables 6 and 8). On the other hand, the September collections bear little resemblance to each other (Tables 7 and 9).

Growth of young fish

A high growth-rate during the pelagic period is indicated by the increase in average length of the young fish sampled between July–August and September 1957. An average increase in length of 14·9 mm in 42 days is much faster than the growth of the adult fish in the same area (Table 10). Average length increased at all depths, increases ranging between 11·2 and 15·5 mm at different depths. The consistency of the changes in length throughout this comparatively broad area suggests that this is a rather precise measure of the growth-rate of young redfish in the Gulf of Maine. The rapid growth agrees with the growth-rate of young-of-the-year redfish previously estimated from less complete data of the pelagic stages (Kelly and Wolf, 1959).

Starting about 25. June, the middle of the usual 4-month spawning period, a 5 mm larva growing at the rate of 14·9 mm per 42 days would attain an average length of 50 mm in 126 days, or by about 28. October. This growth agrees closely with the observed average length of the youngest age-group (pre-annulus) collected in fine-mesh bottom trawls in the Gulf of Maine in November of earlier years. Therefore, it appears that the Gulf of Maine fish are about 4½ months old when they reach a length of 50 mm and move to the bottom.

In reviewing the earlier studies of *Sebastes* cited above, it was noted that fragmentary records of larvae and postlarvae from widely separated areas in the North Atlantic are similar. The time of occurrence and size of specimens observed differed little regardless of where collected. These data are shown together in Figure 5 to compare the growth-rates of larvae throughout the area. The first part includes all data available from the Gulf of Maine. Data from the pertinent collections of Jensen (1922), Dannevig (1919), Frost (1938), and Tåning (1949) from other regions were combined in the second part of Figure 5 (Table 11).

The composite figure gives an almost continuous record of the pelagic growth during the summer and autumn months. A line fitted to the data leads directly to the sizes of fish sampled from the bottom in the Gulf of Maine in the late autumn and winter. Data from all areas fall close to the estimated average growth curve, suggesting that, with local variations, the larval growth-rate in the western North Atlantic is approximately the same.

Duration of pelagic stage

Evidence from the study of early growth indicates a probable average pelagic stage of 4½ months' duration. Assuming that the fry are capable of only local orientation movements, they could be transported great distances by surface water currents in that length of time. The relationship of redfish larvae to the hydrography of the Gulf of Maine and adjacent waters is not adequately understood to formulate a hypothetical

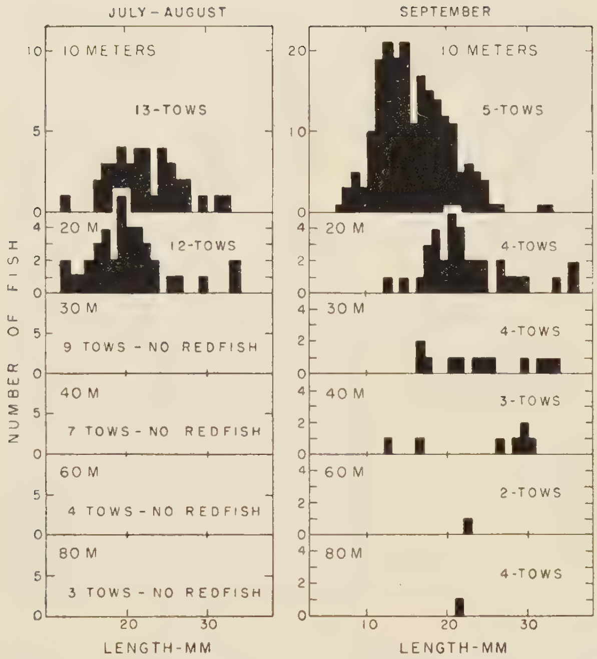


Figure 4. Length composition and depth distribution of young redfish taken by midwater trawl in 1958.

Table 8
Summary of redfish length-frequencies by depth, July—August 1958 ("Albatross III" — Cruise Number 116)

Length (mm)	Depth in metres 10	20	Total
*			
12	1	2	3
13	–	1	1
14	–	1	1
15	–	2	2
16	2	3	5
17	3	4	7
18	3	2	5
19	4	6	10
20	3	4	7
21	4	4	8
22	4	3	7
23	1	2	3
24	4	–	4
25	3	1	4
26	2	1	3
27	2	–	2
28	–	–	–
29	1	1	2
30	–	–	–
31	1	–	1
32	1	–	1
33	–	2	2
Total	39	39	78
Mean length (mm)	22·3	20·2	21·2

* No observations for 5–11 mm lengths.

Table 9
Summary of redfish length-frequencies by depth, September 1958 ("Albatross III" — Cruise Number 117)

Length (mm)	Depth in metres 10	20	30	40	60	80	Total
5	–	–	–	–	–	–	–
6	1	–	–	–	–	–	1
7	3	–	–	–	–	–	3
8	5	–	–	–	–	–	5
9	3	–	–	–	–	–	3
10	10	–	–	–	–	–	10
11	19	–	–	–	–	–	19
12	21	1	–	1	–	–	23
13	19	–	–	–	–	–	19
14	21	1	–	–	–	–	22
15	11	–	–	–	–	–	11
16	17	1	2	1	–	–	21
17	15	3	1	–	–	–	19
18	14	4	–	–	–	–	18
19	12	2	–	–	–	–	14
20	11	5	1	–	–	–	17
21	5	4	1	–	–	1	11
22	6	2	–	–	1	–	9
23	5	2	1	–	–	–	8
24	4	2	1	–	–	–	7
25	1	–	1	–	–	–	2
26	1	2	–	1	–	–	4
27	–	1	–	–	–	–	1
28	–	1	–	1	–	–	2
29	–	1	1	2	–	–	4
30	–	–	–	1	–	–	1
31	1	–	1	–	–	–	2
32	1	–	1	–	–	–	2
33	–	1	1	–	–	–	2
34	–	–	–	–	–	–	–
35	–	2	–	–	–	–	2
Total	206	35	12	7	1	1	262
Mean length (mm)	15·8	22·3	24·4	24·8	22·5	21·5	17·3

Table 10
Increase in average length of young fish, by depth zone, between July—August and September 1957

Depth (m)	July–August (Cruise No. 99) mm	September (Cruise No. 102) mm	Average increase mm
10	22·2	37·7	15·5
20	23·8	36·0	12·2
30	19·5	34·9	15·4
40	24·1	36·6	12·5
60	27·2	38·4	11·2
80	–	40·5	–
100	23·5	38·2	14·7
110	–	37·4	–
Mean length	23·6	38·5	14·9

model of larval drift. The pattern of larval distribution in the present study suggests that the currents in the Gulf of Maine tend to concentrate large numbers of larvae over the deep water in the south and central parts of the Gulf. From what is known of the flow of

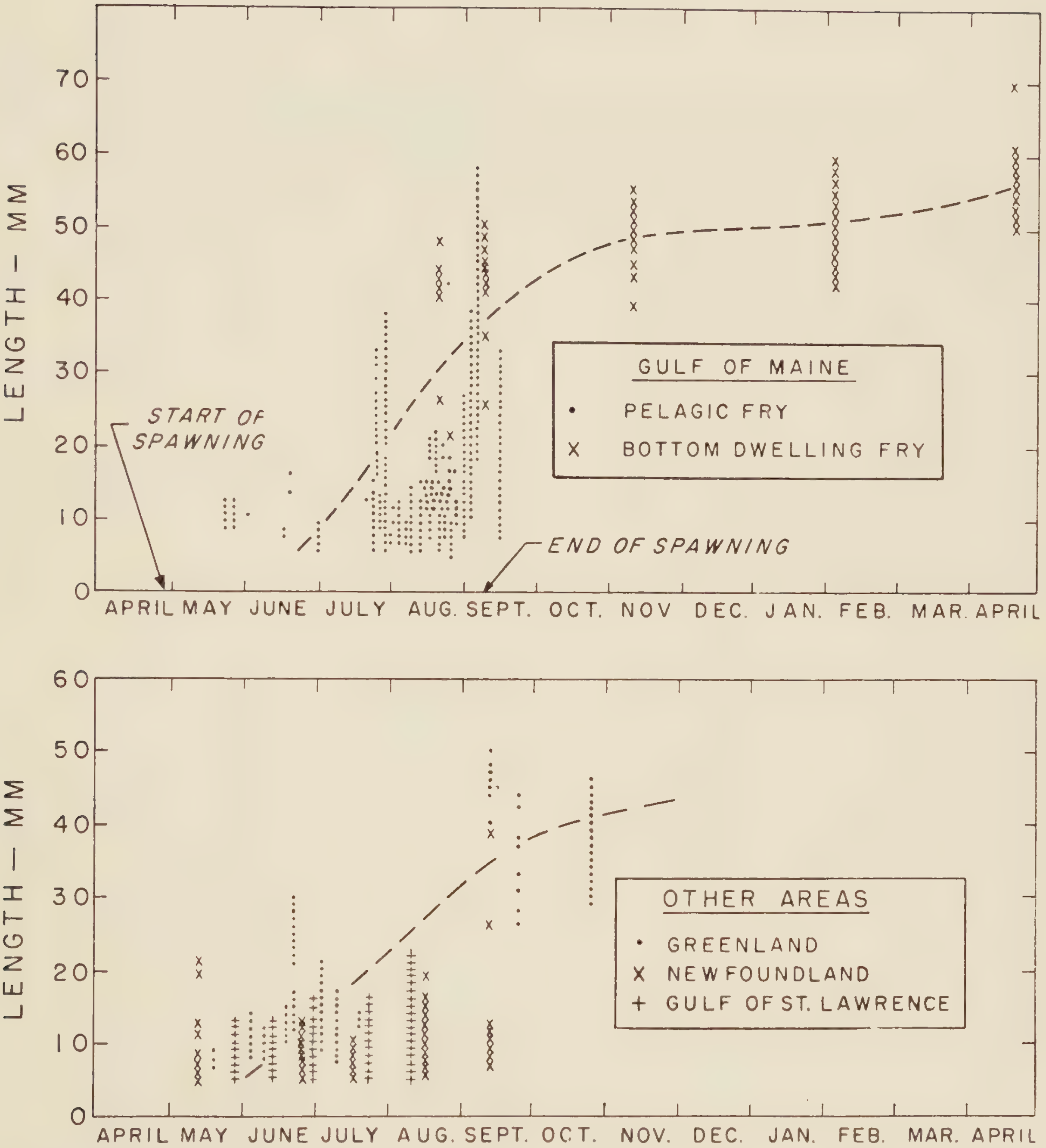


Figure 5. Approximate growth-rate of young redfish in the Gulf of Maine and other north-west Atlantic Ocean areas.

the Nova Scotian shelf water, it is likely that some *Sebastes* larvae originating from the populations on Nova Scotian banks are transported into the Gulf of Maine by the westerly currents around Cape Sable. Specific studies in this area will be necessary to establish this hypothesis.

Assuming the same duration of the pelagic stage in the Iceland–Greenland area, Jensen's theory of long-distance larval transport becomes very plausible. There is ample time for water currents of 3–4 miles per day to carry larvae as much as 500 miles from the location of spawning.

Table 11

Summary of north-west Atlantic larval and postlarval redfish collections pertinent to the study of growth-rate of young fish during the pelagic stage. Source of the data is indicated, with the date of collection, location, size range and number of specimens collected
(Length-frequencies from these collections are used in Figure 5)

Date of collection		Source	Location	Size range (mm)	Number of specimens
1895	18. July	Jensen (1922)	61°44′N–30°29′W	12–14	8
1896	1. June	Jensen (1922)	62°40′N–19°05′W	8·5–14	5
	3. June	Jensen (1922)	62°06′N–22°30′W	7·5–12	9
	12. June	Jensen (1922)	60°30′N–26°54′W	10–15	5
	13. June	Jensen (1922)	60°23′N–27°25′W	12–17	7
1908	14.–26. May	Jensen (1922)	58°59′N–30°50′W to 58°08′N–39°12′W	7–9	Several hundred
1909	25. Sept.	Jensen (1922)	60°05′N–46°35′W	27·5–43·0	9
1912	July	Bigelow (1914)	Gulf of Maine	6–12	314
	August	Bigelow (1914)	Gulf of Maine	5–21	467
1913	June	Jensen (1922)	East coast Greenland	22–30	Great numbers
	24. Oct.	Jensen (1922)	65°40′N	29–45	Some
1914	July	Bigelow (1917)	Gulf of Maine	6–13	281
	August	Bigelow (1917)	Gulf of Maine	7–22	176
1914	29. May–4. June	Dannevig (1919)	Gulf of St. Lawrence	5–13	66
	9.–15. June	Dannevig (1919)	Gulf of St. Lawrence	5–13	108
	21.–29. July	Dannevig (1919)	Gulf of St. Lawrence	5–16	228
	3.–12. August	Dannevig (1919)	Gulf of St. Lawrence	5–22	220
	1. June–18. Aug.	Dannevig (1919)	Gulf of St. Lawrence	5–15	337
1915	May	Bigelow (1917)	Gulf of Maine	10	1
	June	Bigelow (1917)	Gulf of Maine	7–8	2
	August	Bigelow (1917)	Gulf of Maine	6–27	Many
	Sept.	Bigelow (1917)	Gulf of Maine	10–40	Swarm
1915	Sept.	Jensen (1922)	West Greenland	38–49	7
1925	June	Jensen (1926)	West Greenland	7–13	100+
	July	Jensen (1926)	West Greenland	7–17	100+
1931	May	Kelly and Wolf (1959) (Albatross II Coll.)	Gulf of Maine	8–12	13
	June–July	Kelly and Wolf (1959) (Albatross II Coll.)	Gulf of Maine	5–16	84
1932	July	Kelly and Wolf (1959) (Atlantis Coll.)	Gulf of Maine	5–18	2,234
1932–	May	Frost (1938)	Newfoundland area	5–21	40
1935	June	Frost (1938)	Newfoundland area	5–13	249
	July	Frost (1938)	Newfoundland area	5–10	117
	August	Frost (1938)	Newfoundland area	6–19	207
	Sept.	Frost (1938)	Newfoundland area	6–37	13
1947	29. June	Tåning (1949)	56°02′N–38°43′W	9–21	1,072
1953	August	Kelly and Wolf (1959)	Gulf of Maine	26–48	10
	Sept.	Kelly and Wolf (1959)	Gulf of Maine	25–50	17
	Nov.	Kelly and Wolf (1959)	Gulf of Maine	38–54	26
1954	Feb.	Kelly and Wolf (1959)	Gulf of Maine	42–59	83
	April	Kelly and Wolf (1959)	Gulf of Maine	50–67	25
	August	Kelly and Wolf (1959)	Gulf of Maine	5–15	216
1955	August	Kelly and Wolf (1959)	Gulf of Maine	4–21	97
1957	26. July–1. Aug.	(Present Study)	Gulf of Maine	8–38	4,290
	5.–9. Sept.	(Present Study)	Gulf of Maine	17–58	1,438
1958	28. July–1. Aug.	(Present Study)	Gulf of Maine	12–33	78
	14.–15. Sept.	(Present Study)	Gulf of Maine	6–35	262

Summary

Although the depth at which Gulf of Maine redfish larvae are released is not known, the newly spawned larvae (5 to 6 mm) appear at the surface and are concentrated in the upper 10 metres. As they grow to 10–15 mm the larvae move deeper to about 20 m depth where they remain until reaching a length of 25 mm. During this period they stay in the thermocline. When the fish exceed 25 mm they move deeper into the cold water below the thermocline. The movement from the cold middle waters to the bottom is probably influenced by the requirements of individual fish, some going to the bottom when only 25 mm while others 55 to 60 mm in length remain in midwater. Some large postlarvae are found on the bottom as early as August, while others appear to remain in midwater until October.

The relatively long pelagic stage is a period of rapid growth for redfish larvae. The average length attained by the time they move to the bottom appears to be between 40 and 50 mm. This length is reached in 4 or 5 months.

The pelagic period is long enough to permit the fry to drift long distances in the water currents. It is likely that the counterclockwise currents in the Gulf of Maine serve to concentrate the larvae in certain parts of the central area. However, in other less restricted areas, strong surface currents could transport the larvae for distances of several hundred miles.

There is little evidence of diurnal vertical movements of the planktonic larvae. The only obvious diurnal variation is the change in catchability of the larvae at all depths. This suggests that the fish can detect the trawl visually and escape from it during the daylight hours, but are less able to do this at night. The effect could be the reverse if taken in a different view. Perhaps the luminous planktonic animals are stimulated to flare with the approach of the trawl at night, thus attracting the fish toward a source of food and into the path of the net. Despite these variations in availability of the fish, the Isaacs-Kidd midwater trawl is an effective gear for sampling pelagic young redfish.

Great variations in redfish year-class strength undoubtedly occur. Midwater sampling indicates that the 1957 year-class was large and the 1958 class was very small in the southern Gulf of Maine. Several more years of sampling are necessary to determine the normal relative abundance of young-of-the-year redfish in mid-depths.

References

Bigelow, H. B., 1914. "Explorations in the Gulf of Maine, July and August, 1912, by the U.S. Fisheries Schooner 'Grampus'. Oceanography and notes on the plankton." Bull. Mus. comp. Zool. Harv., *58*: 31–147.

Bigelow, H. B., 1917. "Explorations of the coast water between Cape Cod and Halifax in 1914 and 1915, by the U.S. Fisheries Schooner 'Grampus'. Oceanography and plankton." Bull. Mus. comp. Zool. Harv., *61*: 163–357.

Boden, B. P., Kampa, E. M., Snodgrass, J. M., & Devereaux, R. F., 1955. "A depth telerecording unit for marine biology." J. Mar. Res., *14*: 205–09.

Dannevig, Alf, 1919. "Canadian fish-eggs and larvae." Canad. Fish. Exped. 1914–15: 1–74. Ottawa, Dept. Naval Serv.

Frost, N., 1938. "Some fishes of Newfoundland waters (with notes on the distribution of eggs and larvae)." Newfoundland Dept. Natur. Resources, Res. Bull. No. 4: 1–16.

Hjort, J., 1901. "Fiskeforsøg." Chapter 3 in " 'Michael Sars' første Togt i Nordhavet Aar 1900 under Ledelse af Johan Hjort." Aarsberetn. Norg. Fisk. 1900, (4): 251–68.

Isaacs, J. D., & Kidd, L. W., 1953. "Isaacs-Kidd midwater trawl." SIO Ref. 53–3, Jan. 1953: 1–18. Scripps Inst. Oceanogr., Univ. California.

Jensen, Ad. S., 1922. "Researches on the distribution, biology, and systematics of the Greenland fishes." Vidensk. Medd. Dansk Naturh. Foren. Kbh., *74*: 89–109.

Jensen, Ad. S., 1926. "Investigations of the 'Dana' in West Greenland waters, 1925." Rapp. Cons. Explor. Mer, *39*: 85–102.

Kelly, G. F., & Wolf, R. S., 1959. "Age and growth of the redfish (*Sebastes marinus*) in the Gulf of Maine." Fish. Bull. U.S., *60* (156): 1–31.

Leavitt, B. B., 1935. "A quantitative study of the vertical distribution of the larger zooplankton in deep water." Biol. Bull., Woods Hole, *68*: 115–30.

Nansen, F., 1886. "De norske Fiske". Norsk Fiskeritid., No. 5: 66–76.

Perlmutter, A., & Clarke, G. M., 1949. "Age and growth of immature rosefish (*Sebastes marinus*) in the Gulf of Maine and off western Nova Scotia." Fish. Bull. U.S., *51* (45): 207–28.

Schmidt, J., 1904. "Fiskeriundersøgelser ved Island og Færøerne i Sommeren 1903." Skr. Komm. Havunders. Kbh., No. 1.

Steele, D. H., 1957. "The redfish (*Sebastes marinus* L.) in the western Gulf of St. Lawrence." J. Fish. Res. Bd. Can., *14*: 899–924.

Tåning, Å. V., 1949. "On the breeding places and abundance of the red fish (*Sebastes*) in the North Atlantic." J. Cons. int. Explor. Mer, *16*: 85–95.

A/S L. Ihrich, Copenhagen

57

EXTRAIT

Rapp. et Proc.-Verb. Vol. 150, 1961
Cons. Internat. Explor. de la Mer

A.2

Racial Comparisons of Redfish from the Western North Atlantic and the Barents Sea

By
GEORGE F. KELLY, ALLAN M. BARKER, and GEORGE M. CLARKE
Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Introduction

This paper reports the results of a review of meristic and morphometric characteristics that may be of value in redfish racial studies. The study was begun at the request of the Committee on Research and Statistics of the International Commission for the Northwest Atlantic Fisheries. It is not a comprehensive taxonomic study, but is rather a review of a large number of characteristics to serve as a background from which to select a few that might be useful in distinguishing races or populations of redfish for population dynamics studies and management purposes.

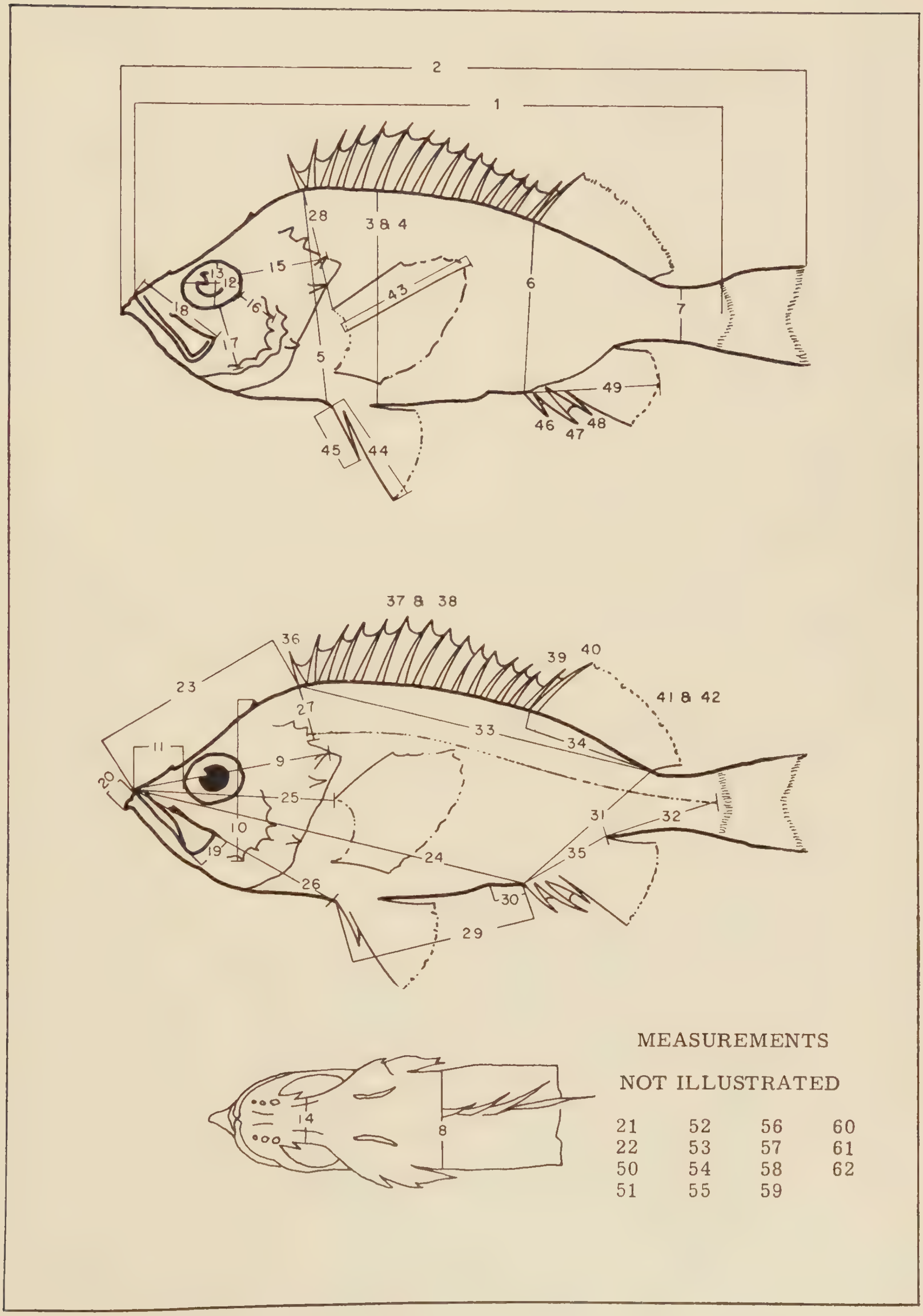
In recent years those working on the commercial fishery have felt some dissatisfaction with the present classification of the entire *Sebastes* group. In the opinion of some workers, the three forms of redfish referred to as *Sebastes marinus, S. mentella,* and *S. viviparus* were not sufficiently different to be classed as full species. It was felt that the genus had not been adequately sampled throughout its range and the normal racial variations were not known. Redfish from widely separated parts of the North Atlantic had never been compared critically.

The classification and nomenclature of the species or subspecies of North Atlantic *Sebastes* has been somewhat confused in the past. The following citations summarize chronologically the pertinent changes in classification of the three main types or species of redfish, *S. marinus, S. mentella* and *S. viviparus,* up to the present time:–

Perca marina (Linnaeus), 1758
Sebastes norvegicus (Cuvier and Valenciennes), 1829
Sebastes viviparus (Krøyer), 1844–45
Sebastes marinus (White), 1851
Sebastes fasciatus (Storer), 1854
Sebastes marinus viviparus (Jordan and Gilbert), 1883
Sebastes mentella (Travin), 1951
Sebastes marinus mentella (Andriiashev), 1954

Until very recently the names *Sebastes marinus* and *S. viviparus* included all of the known stocks of North Atlantic redfish. *S. marinus* was the name applied to the deep-water fish and *S. viviparus* was associated with the shallow-water form of the European coast. Differences in colour, size composition, and depth distribution of the deep-water fish from different geographical areas were known to exist. These were generally considered to be local variations of stocks that were sufficiently similar to fit within the broad limits of the early description of *Sebastes marinus.* At one time even *S. viviparus* was classified as a subspecies of *S. marinus.*

The sampling of new grounds that accompanied the expansion of the commercial fishery beween 1940 and 1946 disclosed redfish having greater variability in body form than had been previously recorded. Some of these were given descriptive common names before Travin (1951) described the large-eyed, long-chinned form as the new species *Sebastes mentella.* While his was the first step toward clarifying the status of the many *Sebastes* groups presently exploited by the modern fishery, Travin's naming of *S. mentella* posed the question whether each separable group of *Sebastes* qualified as a new species or simply as a local variation of *S. marinus.* Andriiashev (1954) questioned the validity of *S. mentella* as a full species, on the grounds that the variability of the characteristics used to describe it was not adequately known for the populations of redfish throughout the range in the North Atlantic. Andriiashev's view that differences of this magnitude could be at the subspecific level is shared by others. It is the purpose of this study to show the degree of variation of some of the characteristics that have been used in describing groups of redfish in the past. These results may direct future studies toward characteristics most likely to produce valid separations.


2
1
28
3 & 4
15
13
12
18
16
17
5
43
6
7
49
45
44
46
47
48
37 & 38
36
39
40
41 & 42
23
27
33
34
11
9
20
25
10
19
26
24
31
32
35
30
29
14
8

MEASUREMENTS

NOT ILLUSTRATED

21
22
50
51
52
53
54
55
56
57
58
59
60
61
62

Figure 1. Illustration of racial measurements used in the study (see App. I).

Methods

The three general areas: the Barents Sea, Iceland, and the Northwest Atlantic were initially established by the ICNAF committee as the sampling areas that were most likely to include the widest range of variation in racial characteristics. During 1958 samples of redfish were obtained from the Barents Sea in the east and from the Labrador coast, the Gulf of St. Lawrence, and the Gulf of Maine in the western Atlantic. Unfortunately it was not possible to obtain samples from Iceland in time for the material to be included in this study.

At the outset of the study a comprehensive list of 62 meristic and morphometric characteristics was compiled for consideration (Figure 1 and Appendix I). The definitions of terms and the methods of counting and measuring body parts follow the recommendations of Hubbs and Lagler (1958) as closely as possible.

Because of the limitations of time only a few of the measurements could be made on each fish. In order to concentrate on the *marinus-mentella* separation, the greatest number of measurements were made on fish from the areas displaying the greatest range in eye size, namely the Barents Sea and the Gulf of St. Lawrence. The location of the areas sampled, the list of measurements, and the number of fish measured from each area are summarized in Table 1. The results of earlier work on a selected few meristic and morphometric measurements are included for comparison with the more recent data. These include material from the Gulf of St. Lawrence, the Grand Banks, three areas on the Nova Scotian Banks, and six areas in the Gulf of Maine (Figure 2).

Table 1

Location and date of collection of samples and list of characteristics and number of fish measured

(See Appendix I and Figure 2)

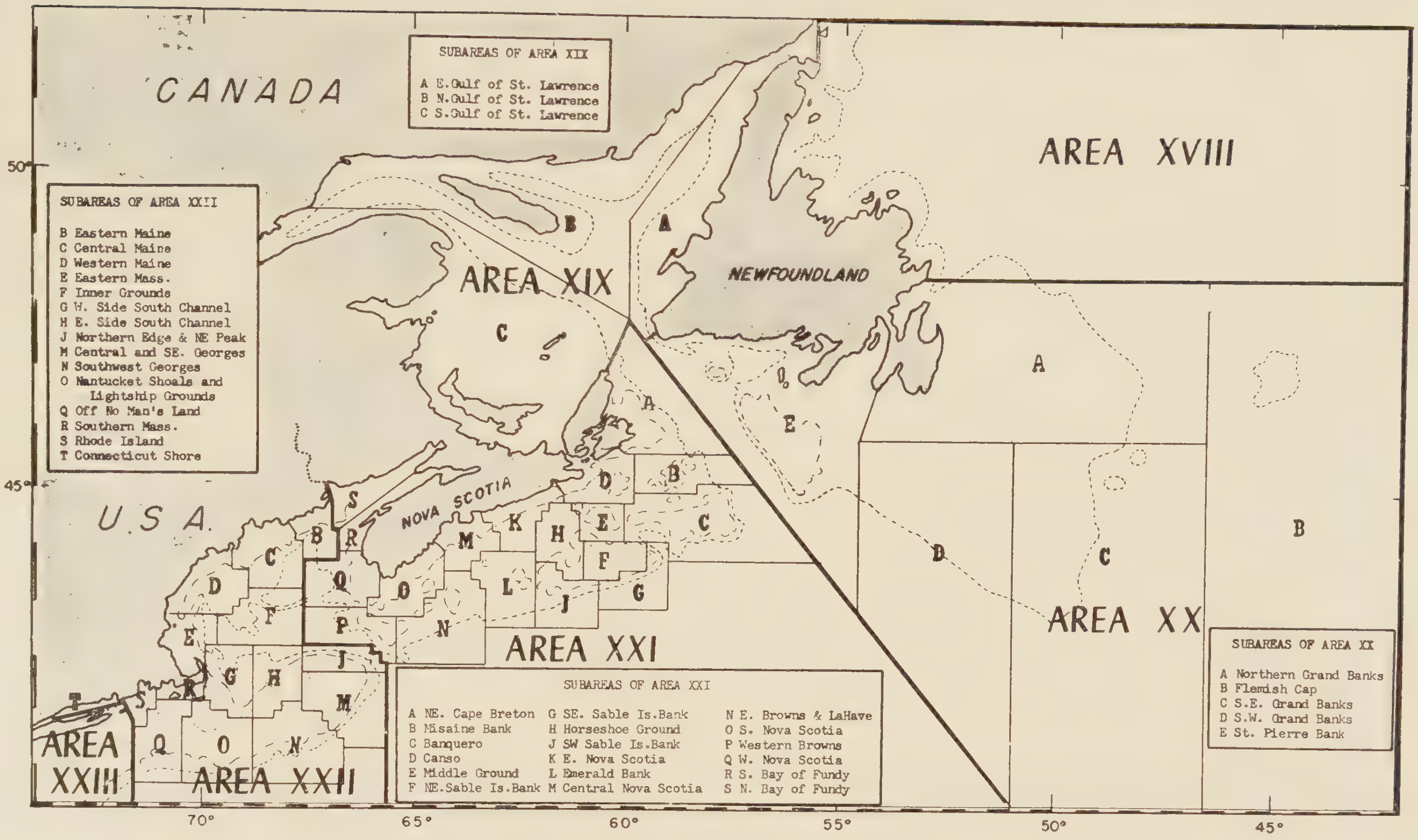
Area	Sample number	Date collected	Latitude and longitude	Depth (fm)
Barents Sea	1	July 2, 1958	74° 26–29′ N– 16° 23′ E	195–220
	6	Sept. 9, 1958	74° 20–24′ N– 16° 24–26′ E	190–215
Labrador	3	Sept. 8, 1958	54° 00′ N– 54° 30′ W	135–150
	4	Aug. 30, 1958	54° 00′ N– 54° 30′ W	135–165
Eastport	7	July-Aug. 1958	44° 55′ N– 67° 00′ W	0–5
Gulf of St. Lawrence	2 {12 22	Aug. 14, 1958	50° 25′ N– 58° 40′ W	125–150

Characteristic number (See Appendix I)	Characteristic	Sample number 1	2	3	4	6	7
1	Standard length	93	198	103	36	48	50
2	Total length	93	198	103	36	48	50
5	Body depth, dorsal to ventral	93	198	103	36	48	50
6	Body depth, dorsal to anal	93	198	47	–	48	50
7	Depth of caudal peduncle	93	198	103	36	–	–
9	Head length	93	198	103	36	48	50
10	Parietal sp. to ant. preop. sp.	93	198	47	–	–	–
11	Snout length	93	198	47	–	48	50
12	Horizontal diam. of orbit	93	198	103	36	48	50
13	Vertical diam. of orbit	93	198	47	–	–	–
14	Interorbital width	93	198	103	36	48	50
15	Postorbital length	93	198	103	36	48	50
16	Orbit to dorsal preop. sp.	93	198	47	–	–	–
17	Orbit to anterior preop. sp.	93	198	47	–	–	–
18	Length of upper jaw	93	198	47	–	48	50
19	Width of posterior maxillary	93	198	47	–	48	50
20	Length of schnabel	93	198	103	36	48	50
23	Snout to dorsal fin	93	198	47	36	–	–
24	Snout to anal fin	93	198	47	–	–	–
25	Snout to pectoral fin	93	198	47	–	–	–
26	Snout to ventral fin	93	198	47	–	–	–
50	Dorsal fin count	93	99	47	–	48	50
51	Anal fin count	93	99	47	–	48	50
52	Pectoral fin count	93	99	47	–	48	50
54	Caudal fin count	93	99	47	–	48	50
58	No. of gill rakers, 1st arch	93	99	47	–	48	50

Results

There was a wide variation in the range of lengths of fish sampled from different areas (Figure 3). In some instances (e.g. Eastport and Labrador) the ranges of two groups did not overlap. This lack of consistency in size range had no effect on the meristic comparisons but was of importance in comparing the regressions of the morphometric characteristics. Regression lines of the small fish could not be extrapolated to the larger sizes with accuracy.

Meristic characteristics are summarized in Tables 2 to 5. Appendix II contains the unpublished redfish meristic notes of Å. Vedel Tåning, the only other material available for meristic comparisons of *Sebastes*. In the new data the number of dorsal spines ranges from thirteen to eighteen, the mode at fifteen in all areas. The modal number of soft rays in the dorsal fin is thirteen in the Gulf of Maine and Nova Scotian waters and fourteen in the areas to the north and east. The mean number of spines and rays in the dorsal fin shows a general increase from the Gulf of Maine north-


CANADA
U.S.A.
NEWFOUNDLAND
NOVA SCOTIA
AREA XVIII
AREA XIX
AREA XX
AREA XXI
AREA XXII
AREA XXIII
SUBAREAS OF AREA XIX
A E.Gulf of St. Lawrence
B N.Gulf of St. Lawrence
C S.Gulf of St. Lawrence
SUBAREAS OF AREA XXII
B Eastern Maine
C Central Maine
D Western Maine
E Eastern Mass.
F Inner Grounds
G W. Side South Channel
H E. Side South Channel
J Northern Edge & NE Peak
M Central and SE. Georges
N Southwest Georges
O Nantucket Shoals and Lightship Grounds
Q Off No Man's Land
R Southern Mass.
S Rhode Island
T Connecticut Shore
SUBAREAS OF AREA XXI
A NE. Cape Breton
B Misaine Bank
C Banquero
D Canso
E Middle Ground
F NE.Sable Is.Bank
G SE. Sable Is.Bank
H Horseshoe Ground
J SW Sable Is.Bank
K E. Nova Scotia
L Emerald Bank
M Central Nova Scotia
N E. Browns & LaHave
O S. Nova Scotia
P Western Browns
Q W. Nova Scotia
R S. Bay of Fundy
S N. Bay of Fundy
SUBAREAS OF AREA XX
A Northern Grand Banks
B Flemish Cap
C S.E. Grand Banks
D S.W. Grand Banks
E St. Pierre Bank
50°
45°
70°
65°
60°
55°
50°
45°

STATISTICAL AREAS — 1955

71533

Figure 2. Statistical subareas of the Northwest Atlantic Ocean. (U.S. Fish and Wildlife Service designation based on boundaries established by North American Council on Fishery Investigations.)

Area	Sample	Number of Specimens
Barents Sea	#1	93
	#6	48
Gulf of St. Lawrence	#2 { 12 22	198
Labrador	#3	103
	#4	36
Eastport	#7	50
Gulf of St. Lawrence XIX A	From earlier studies (1956)	424
Grand Banks XX C	"	160
D	"	212
Nova Scotia Banks XXI C	"	100
H	"	175
O	"	148
Gulf of Maine XXII C	"	129
D	"	181
E	"	802
F	"	172
G	"	159
H	"	126

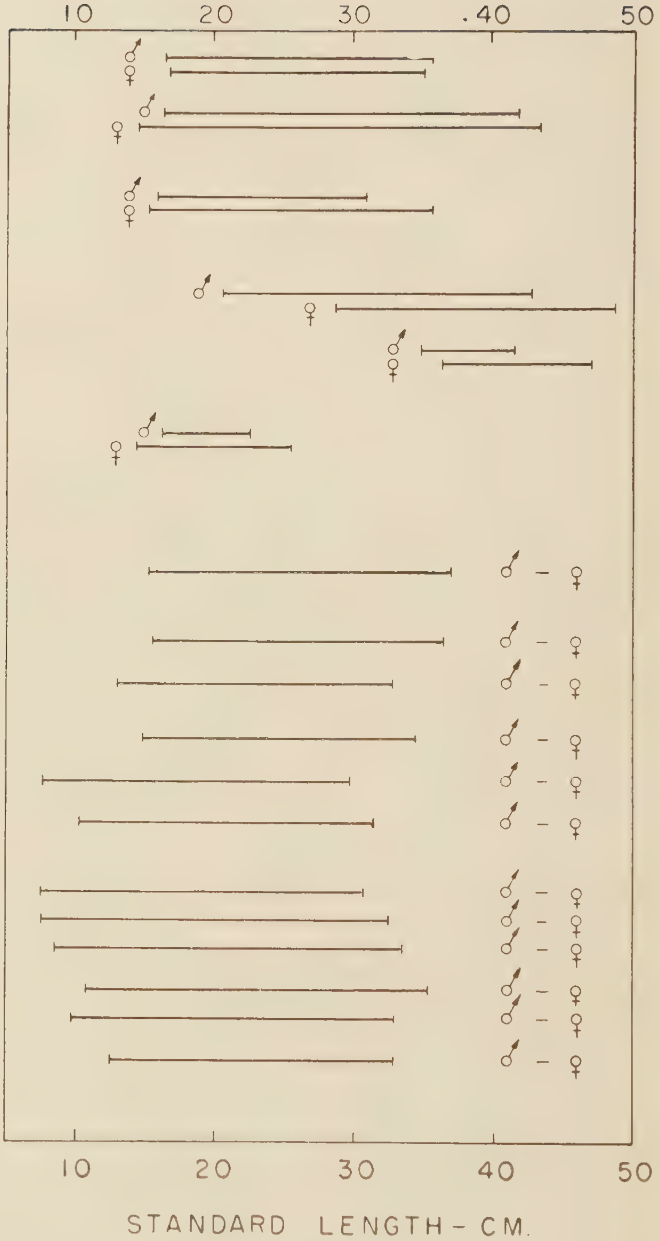


Figure 3. Range of standard lengths of specimens from different areas.

Table 2
Number of spines and soft rays in the dorsal fin of redfish from different areas
(see Figure 1)

Area	XIII		XIV						XV				XVI					XVIII	
	13	14	11	12	13	14	15	16	12	13	14	15	12	13	14	15	16	13	Total
Barents Sea																			
Sample 1	–	–	–	–	–	–	1	–	1	29	*45*	17	–	–	–	–	–	–	93
Sample 2	–	–	–	–	–	1	–	1	–	1	15	*25*	–	–	1	–	1	–	45
Area XVII (Labrador Coast)	–	–	–	–	–	–	–	–	–	21	*24*	1	1	–	–	–	–	–	47
Area XIX (Gulf of St. Lawrence)																			
Subarea A1	–	–	–	–	–	–	6	2	1	6	*54*	26	–	1	2	1	–	–	99
Subarea A2	–	–	–	–	–	1	3	–	–	34	*46*	14	–	1	–	–	–	–	99
Subarea C	–	–	–	–	–	–	1	–	–	6	*13*	1	–	–	–	–	–	–	21
Area XX (Grand Bank)																			
Subarea C	–	–	–	–	1	–	–	–	–	3	*12*	1	–	3	–	–	–	–	20
Subarea E	–	–	–	–	–	1	1	–	–	8	*9*	1	–	–	–	–	–	–	20
Area XXI (Nova Scotia Banks)																			
Subarea C	1	–	–	–	–	2	–	–	1	*6*	*6*	2	–	–	–	2	–	–	20
Subarea O	–	–	–	–	–	–	–	–	1	*14*	11	–	–	–	–	–	–	–	26
Subarea N	–	–	1	–	–	1	–	–	–	*38*	30	2	1	4	–	–	–	–	77
Area XXII (Gulf of Maine)																			
Eastport	–	–	–	–	–	–	–	–	11	*70*	22	–	2	1	–	–	–	–	106
Subarea C	–	–	–	–	–	–	–	–	–	*17*	4	–	–	–	–	–	–	–	21
Subarea D	–	1	–	–	–	3	1	–	2	*16*	13	–	–	1	–	–	–	–	37
Subarea E	–	–	–	–	1	2	–	–	–	*30*	24	2	–	1	1	–	–	–	61
Subarea G	–	–	–	–	–	1	–	–	–	*10*	8	–	–	1	–	–	–	–	20
Subarea M	–	–	–	–	–	2	–	–	–	*42*	32	–	–	1	1	–	–	1	79
Total	1	1	1	–	2	14	13	3	17	351	*368*	92	4	14	5	3	1	1	891

(Column groups XIII–XVIII are SPINES; numbers beneath are SOFT RAYS.)

ward to the Barents Sea, suggesting a possible clinal distribution of the characteristic in the whole population complex (Table 3). All of these values fall between the highest and lowest values shown by Tåning for *marinus* and *viviparus* respectively.

The number of spines and rays in the anal fin and pectoral fin display variations within each sample and area, but there is no apparent pattern of consistent differences between areas. There is perhaps the suggestion of an increasing gradient from south to north. Tåning's values for *viviparus* are consistently at the lower end of the range of values for the other samples.

The number of gill rakers ranges from 30 to 40 in the new samples, compared with 30 to 41 in Tåning's *marinus-viviparus* data. Sample modes range between 34 and 36 for *marinus* in all areas, compared with 38 for *viviparus*. The mean number of rakers suggests a decreasing gradient from south to north, the reverse of the distribution indicated by the other meristics.

Table 3
Dorsal fin counts

Area	Number of rays 25	26	27	28	29	30	31	32	Total no. of fish	Mean no. of rays
Barents Sea	–	–	1	31	*61*	44	–	1	138	29·12
Area XVII Labrador	–	–	–	22	*24*	1	–	–	47	28·55
Area XIX Gulf of St.Lawrence	–	–	1	47	*125*	45	1	–	219	29·00
Area XX Grand Banks	–	–	1	12	*25*	2	–	–	40	28·70
Area XXI Nova Scotia	1	1	2	*62*	51	4	2	–	123	28·47
Area XXII Gulf of Maine	–	–	15	*195*	109	4	1	–	324	28·32
Total number of rays	1	1	20	369	*395*	100	4	1	891	

Table 4
Number of rays in anal fin and pectoral fin of redfish from different areas
(see Figure 1)

Area	Number of rays Anal fin 9	10	11	12	13	Total number of fish	Mean number of rays	Number of rays Pectoral fin 18	19	20	Total number of fish	Mean number of rays
Barents Sea	–	33	*74*	30	1	138	10·99	9	*115*	13	137	19·03
Area XVII Labrador Coast	3	*32*	12	–	–	47	10·19	2	*35*	9	46	19·15
Area XIX Gulf of St Lawrence												
A	1	61	*100*	36	1	199	10·87	11	*150*	35	196	19·12
C	–	–	*21*	–	–	21	11·00	–	*16*	5	21	19·24
Area XX Grand Banks												
C	1	*17*	2	–	–	20	10·05	3	*15*	2	20	18·95
E	–	*15*	5	–	–	20	10·25	–	*19*	1	20	19·05
Area XXI Nova Scotia Banks												
C	–	*9*	7	4	–	20	10·75	2	*15*	3	20	19·05
N	1	*66*	10	–	–	77	10·12	4	*68*	5	77	19·01
O	–	*19*	7	–	–	26	10·27	4	*20*	2	26	18·92
Area XXII Gulf of Maine												
B	22	*80*	4	–	–	106	9·83	35	*71*	–	106	18·67
C	1	*20*	–	–	–	21	9·95	4	*17*	–	21	18·81
D	–	–	–	–	–	–	–	6	*30*	1	37	18·86
E	2	*53*	6	–	–	61	10·17	17	*44*	–	61	18·72
G	–	*16*	4	–	–	20	10·20	4	*15*	1	20	18·85
M	–	*59*	20	–	–	79	10·25	2	*69*	8	79	19·08
Total	31	*480*	272	70	2	855	10·45	103	*699*	85	887	18·98

Table 5
Number of gill rakers on first gill arch of redfish from different areas
(see Figure 1)

Area	Number of rakers 30	31	32	33	34	35	36	37	38	39	40	Total number of fish	Mean number of rakers	
Barents Sea	–	–	6	37	*55*	30	8	1	–	–	–	137		34·00
Area XVII Labrador Coast	–	–	2	9	*17*	15	4		–	–	–	47		34·21
Area XIX Gulf of St. Lawrence														
A	–	–	1	11	50	54	*57*	20	4		1	198	34·81	34·64
C	1	–	3	11	*20*	9	4	–	–	–	–	48	33·92	
Area XXI Nova Scotia														
N	–	–	–	5	6	*34*	17	12	2	1	–	77		35·45
Area XXII Gulf of Maine														
B	–	–	–	3	21	*37*	17	3	1			82	34·84	34·82
C	–	–	1	–	6	*8*	4	1	–	–	–	20	34·80	
D	–	–	–	–	1	3	6	–	–	–	–	10		
M	–	–	–	6	4	*11*	3	–			–	24		
Total	1	–	13	82	180	*201*	120	37	7	1	1	643		

Tåning's *viviparus* is obviously different from all other samples in gill raker number, despite its similarity to the Gulf of Maine fish in dorsal, anal, and pectoral fin count.

Tåning's count of the number of scale pouches below the lateral line (Appendix I) is undoubtedly the best characteristic for separating *viviparus* from the other redfish groups. Whether it is of value in *marinus-mentella* separation is not known. The count is best done on fresh specimens. Since most of the available material for the present study was preserved in formaldehyde, this count was not taken.

The quantity of morphometric data at hand is too great for presentation in this paper. Regressions were computed for the relationship of each morphometric characteristic on standard length. Regression lines for the same characteristic from each sample were compared in order to classify the degree of variation. Three categories were established and were approximately defined in terms of regression slope and standard deviation as follows:–

Group A – Greatest variation – When one or more regression lines did not intercept all other regression lines within the range of the data, and when the values of the means (plus or minus 2 standard deviations) of two or more samples did not overlap each other.

Group B – Medium variation – When one regression line did not intercept all others at or near their point of convergence, and when the values of the means (plus or minus 2 standard deviations) of two or more samples showed little overlap.

Group C – Least variation – When all regression lines converged at or near a common intercept point, or when each value of the mean (plus or minus 2 standard deviations) overlapped all others.

Under these terms, the characteristics arranged themselves into the groups as follows:–

Group A – Greatest variation
12 Horizontal diameter of orbit/Standard length
13 Vertical diameter of orbit/Standard length
5 Body depth (dorsal fin to ventral fin)/Standard length
26 Snout to ventral fin/Standard length
24 Snout to anal fin/Standard length

Group B – Medium variation
20 Schnabel length/Standard length
15 Postorbital length/Standard length
14 Interorbital width/Standard length
6 Body depth (dorsal fin to anal fin)/Standard length
23 Snout to dorsal fin/Standard length
25 Snout to pectoral fin/Standard length
16 Orbit to most dorsal preopercular spine/Standard length
10 Parietal spine to most anterior preop. spine/Standard length

Group C – Least variation
9 Head length/Standard length
11 Snout length/Standard length
18 Length of upper jaw/Standard length
7 Caudal peduncle depth/Standard length
19 Postmaxillary width/Standard length
17 Orbit to most anterior preopercular spine/Standard length

Examples from each category are presented in Figure 4. The vertical scale in the figure is exaggerated to show the small differences in the lines which would otherwise be obscured. The means and standard deviations were computed for each regression, using a standard length of 250 mm, for all samples. This method of presentation reduces the bias caused by inadequate sampling and permits comparison of the degree of overlap of each characteristic between samples.

Diameter of orbit appears to be the morphometric characteristic showing the most consistent pattern of variation and is the most promising for separating groups of *Sebastes*. Although Travin (1951) associated large eye size with long schnabel, the regressions of schnabel on standard length indicate that it is a less reliable characteristic than eye size for separating groups.

The Gulf of St. Lawrence sample was separated into two groups on the basis of eye size in order to compare the variation of other characteristics in large-eyed and small-eyed fish. There was a natural separation in that sample at an orbit diameter of 35·0 mm. The small-eyed fish were called sample No. 12 and the large-eyed fish sample No. 22. Sample No. 22 contained, on the whole, larger fish and in most of the regression comparisons it stands out as widely different from all other samples, as would be expected in a selected sample.

A comparison was made of the large-eyed and small-eyed (Gulf of St. Lawrence) fish to determine whether differences in some of the meristic characteristics were associated with eye size. The average number of gill rakers and number of dorsal spines and rays were computed for both groups. The mean values are:–

Sample No.	Number of fish	Mean standard length (mm)	Mean diameter of orbit (mm)
12	42	275·3	30·7 ratio ·111
22	49	304·3	40·9 ·134

Sample No.	Number of fish	Mean number of gill rakers	Mean number of dorsal rays
12	42	34·74	29·17
22	49	34·78	29·30

The extremely small difference in mean value of the meristics between samples of fish differing so greatly in mean orbit diameter indicates that variations in orbit size are not related to variations in meristic numbers.

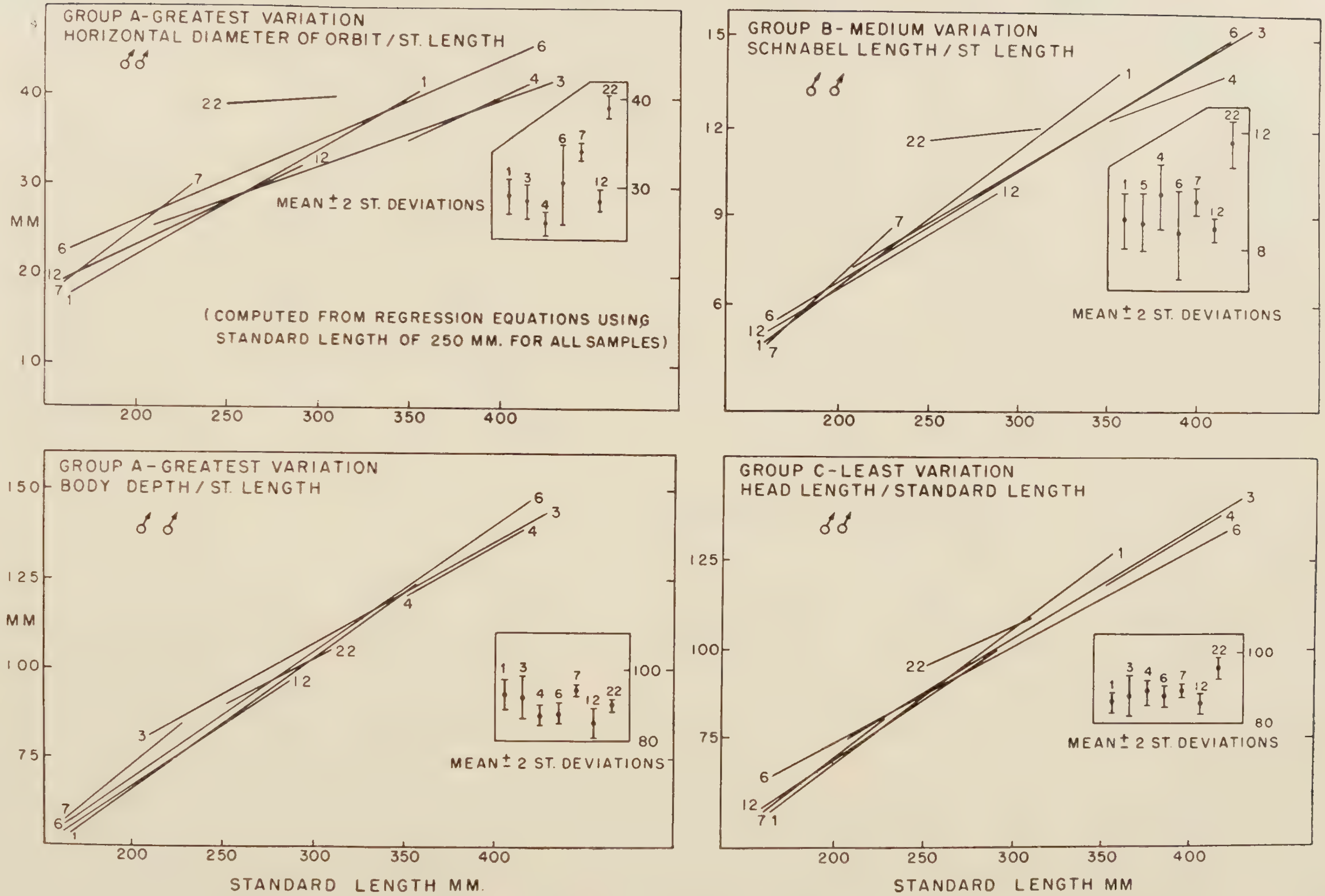


Figure 4. Examples of morphometric regressions illustrating the three categories of variation.

Table 6

Means and confidence limits (± 2 standard deviations) of measurements for males, computed with standard length equal to 250 mm

Measurement	Barents Sea		Labrador		Eastport	St. Lawrence	
Sample Nos.	1	6	3	4	7	12	22
Group A							
Horizontal diameter of orbit	28·9 ± 4·4	30·5 ± 8·2	28·4 ± 4·4	25·8 ± 2·8	33·9 ± 2·2	28·4 ± 2·2	39·0 ± 3·0
Vertical diameter of orbit	28·0 ± 4·2	–	26·9 ± 3·2	–	–	27·3 ± 2·2	36·9 ± 3·2
Body depth (dorsal to ventral fin)	93·5 ± 8·1	86·8 ± 7·0	91·7 ± 14·8	86·5 ± 7·2	94·7 ± 3·7	83·9 ± 7·6	88·6 ± 7·4
Snout to ventral fin	101·1 ± 6·6	–	96·8 ± 7·4	–	–	94·8 ± 7·2	96·3 ± 7·2
Snout to anal fin	170·0 ± 8·2	–	178·6 ± 13·0	–	–	173·0 ± 11·8	175·7 ± 11·6
Group B							
Body depth (d. to a. fin)	65·8 ± 5·0	69·7 ± 10·4	69·1 ± 10·2	–	68·0 ± 5·4	65·3 ± 5·4	62·3 ± 6·2
Snout to dorsal fin	89·3 ± 8·8	–	92·1 ± 9·8	86·3 ± 7·0	–	87·1 ± 6·0	100·2 ± 7·0
Snout to pectoral fin	86·7 ± 5·6	–	84·5 ± 7·0	–	–	83·6 ± 5·6	87·3 ± 6·6
Schnabel length	9·0 ± 1·8	8·4 ± 3·4	8·9 ± 2·0	9·9 ± 1·8	9·7 ± 1·0	8·6 ± 1·0	11·5 ± 1·6
Interorbital width	18·5 ± 2·0	18·6 ± 2·2	19·8 ± 3·6	18·2 ± 3·0	18·0 ± 1·2	17·6 ± 1·6	18·5 ± 4·2
Postorbital length	37·8 ± 3·0	36·2 ± 3·8	38·9 ± 6·4	41·0 ± 4·0	36·9 ± 1·4	39·1 ± 3·2	39·0 ± 4·0
Orbit to dorsal preop. spine	20·4 ± 2·6	–	20·7 ± 3·8	–	–	20·9 ± 2·2	17·8 ± 2·8
Parietal sp. to dorsal preop. spine	63·6 ± 4·0	–	64·7 ± 6·2	–	–	62·9 ± 4·0	72·2 ± 3·2
Group C							
Orbit to anterior preop. spine	25·7 ± 2·0	–	26·1 ± 3·0	–	–	25·9 ± 2·2	25·5 ± 2·6
Head length	86·1 ± 5·0	87·5 ± 4·6	88·0 ± 11·2	88·5 ± 5·2	89·2 ± 3·0	86·0 ± 4·4	95·6 ± 5·6
Snout length	21·5 ± 2·2	–	21·7 ± 3·4	–	19·7 ± 1·8	20·1 ± 2·4	20·4 ± 2·4
Upper jaw length	42·2 ± 2·6	42·4 ± 3·8	41·8 ± 3·2	–	42·2 ± 1·2	41·4 ± 2·6	43·5 ± 3·2
Postmaxillary width	14·6 ± 2·6	14·7 ± 2·2	15·6 ± 2·2	–	16·5 ± 1·4	14·3 ± 1·6	14·9 ± 1·6
Caudal peduncle depth	21·4 ± 2·4	–	25·1 ± 4·6	23·6 ± 4·0	–	22·8 ± 2·2	23·4 ± 2·4

Since eye size is the characteristic that consistently shows the greatest variations in relation to other body dimensions, an attempt has been made to compare the ratio of diameter of orbit/standard length for all samples available with sexes separate. The ratios range from 0·085 to 0·155 with a rather broad range of values in each sample (Figure 5). The values were smoothed by threes and plotted as percentages. It is interesting to note that in most areas a unimodal or trimodal distribution occurs, rather than a simple bimodal distribution that should occur if a clear separation of *marinus* and *mentella* were possible. The Labrador fish have an orbit/length ratio distinctly different from all other groups. The highest ratio is present in the Gulf of St. Lawrence and on the Nova Scotian banks, values well above the Barents Sea mode. In fact, the major mode in the Barents Sea distribution coincides with the lowest of three ratio modes present in the Gulf of St. Lawrence. Whatever the number of orbit/length ratio groups represented in the samples, when they are added together the total sample distribution tends toward a normal distribution. While this ratio comparison is admittedly a rough approximation, perhaps uniform sampling across the North Atlantic will disclose a normal distribution of eye size for the whole *Sebastes* population complex.

Discussion

From the data presented in this study it would be difficult to determine whether the forms of *Sebastes* represented in the samples are genetically or environmentally controlled. It is clear that relative orbit diameter is a variable characteristic in all groups of *Sebastes* sampled. In most comparisons of eye size it is assumed that the orbit diameter/standard length ratio is genetically fixed and is constant throughout the life of the fish. Some of the data suggest that this may not be true. The mystery of the origin of the large-eyed fish in the Gulf of St. Lawrence is a case in point. Random samples of the commercial catch show a constant ratio in fish up to a total length of about 30 cm. From 30 cm upward, a large-eyed group of fish is present that is not represented at smaller lengths. This condition could be the result of the smaller fish of the large-eyed group being unavailable to the otter trawl for a period of years because of sustained pelagic existence. However, it could also be the result of adverse ecological conditions such as inadequate food supply, invasion of parasites or disease resulting in detrimental effects to the well-being of the fish. Emaciation of the larger fish might lead to a change in the orbit diameter/standard length ratio.

Although it is impossible to enumerate the racial

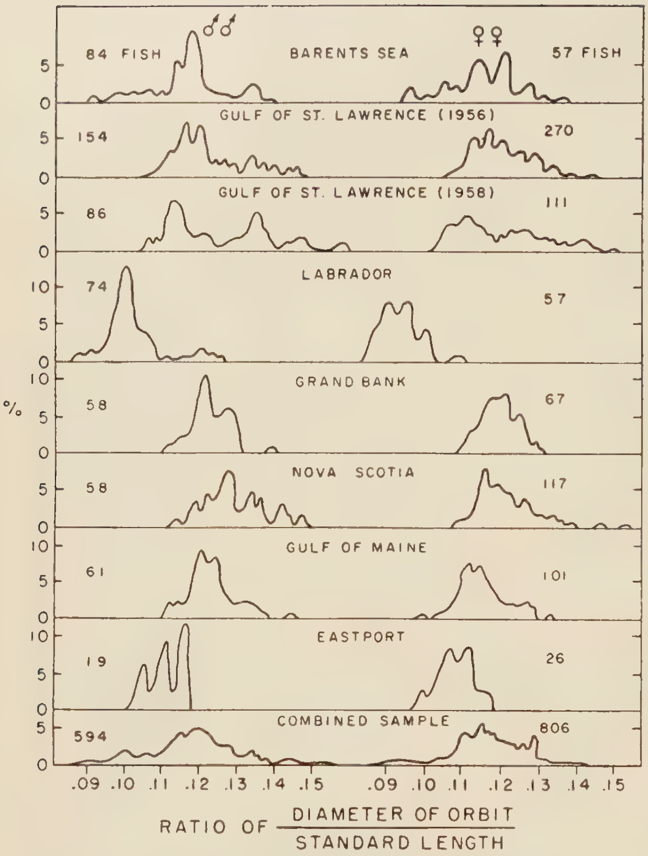


Figure 5. Percentage composition of diameter of orbit/standard length ratio by area, sexes separate.

characteristics of *Sebastes* that are genetically or environmentally influenced, now that meristic and morphometric data have been studied in detail and comparatively small differences across the whole range of *Sebastes* have been found, other factors must be scrutinized in the same detail. It is necessary to establish the validity of previously reported relationships between racial characteristics and environmental conditions before those which are the diagnostic characteristics can be determined. Some attributes that have been linked with ecological factors may in fact be largely independent of environment. The present interpretation of the *Sebastes* racial structure is influenced by these environmental relationships which may be valid in local populations but which do not apply to the whole *Sebastes* complex. In the earlier racial separations of *S. marinus*, *S. mentella*, and *S. viviparus*, characteristics such as comparative eye size, growth rate, time of spawning, and depth distribution were cited as evidence of the separateness of groups that suggested species differences. Each of these could be genetically or environmentally related and could represent differences between species or merely local racial variations.

Perhaps some basic ecological relationships can be established if the same problems in all parts of the *Sebastes* range are considered. The following questions are submitted for the consideration of investigators in future redfish studies:–

1. Is there good evidence indicating that two groups of *Sebastes* spawn in the same area at widely different times?
2. Has a positive relationship between increasing orbit diameter/standard length ratio and greater water depth been shown for *Sebastes*?
3. What is the effect of fast or slow growth on body proportions of fish from the same population? Does early or late maturity result in measurable differences in body form?
4. Is there evidence from any species that an extended pelagic period of life could result in body form different from that of the bottom-dwelling stocks of the same species?
5. Is there evidence from any species of changes in body proportions caused by changes in nutrition or the invasion of parasites or disease?

Conclusions

This review of meristic and morphometric characteristics has served to broaden the view of the *Sebastes* racial variations, and has narrowed the range of characteristics to be investigated. More widespread sampling of the whole *Sebastes* group is necessary. The measurement of a few selected meristic and morphometric characteristics in conjunction with studies of serology, genetics, and incidence of parasites and disease in key areas of the range should provide satisfactory answers to the present problems of *Sebastes* classification.

References

Andriiashev, A. P., 1954. "XLII. Family Scorpaenidae." In: "Fishes of the northern seas of Russia". Guides to the fauna of the U.S.S.R. published by the Zoological Institute of the Academy of Sciences of the U.S.S.R., Moscow and Leningrad, No. 53, 329–339. (Translated by C. Richard Robins).

Hubbs, C. L., & Lagler, K. F., 1958. "Fishes of the Great Lakes region." Cranbrook Inst. Sci., Bull. No. 26: 1–213.

Jordan, D. S., & Evermann, B. W., 1898. "Fishes of North and Middle America." U.S. Nat. Mus., Bull., *47*, pt. 2, p. 1759.

Travin, V. I., 1951. "A new species of sea perch in the Barents Sea (*Sebastes mentella* Travin sp. nov.)." Dokl. Akad. Nauk SSSR, *77* (4): 741–44. (Translated by C. Richard Robins).

APPENDIX I

Definitions of Redfish Racial Measurements

1. Standard length. The distance from the most anterior part of the snout or upper lip at the midline to the caudal base.

2. Total length. The greatest dimension between the most anteriorly projecting part of the head (the tip of the lower jaw with the mouth closed) and the farthest tip of the caudal fin when the rays are spread normally.

3. Greatest depth of body. The greatest vertical dimension of the body exclusive of fins.

4. The number of the dorsal spine beneath which the body is most deep.

5. Body depth at origin of dorsal fin to origin of ventral fin. The least dimension between the base of the first dorsal spine and base of the ventral spine.

6. Body depth at base of last dorsal spine to base of first anal spine. Distance from base of last dorsal spine (i.e. the spine just ahead of the soft rays) to the base (anterior edge) of the first anal spine.

7. Least depth of caudal peduncle.

8. Width of body between uppermost points of gill openings. The body width measured at the points where the gill flap joins the body.

9. Length of head. The distance from the most anterior part of the snout or upper lip at the midline to the posterior point of the opercular spine.

10. Tip of last parietal spine to tip of most anterior preopercular spine (a measure of head depth).

11. Length of snout. The least dimension between most anterior point of upper jaw at the midline and the nearest point on the orbit.

12. Diameter of orbit – horizontal.

13. Diameter of orbit – vertical.

14. Interorbital width. Least bony interorbital width.

15. Postorbital length. Least dimension between the tip of the spine on gill flap to the nearest point on the orbit.

16. Distance between orbit and tip of most dorsal preopercular spine.

17. Orbit to most anterior preopercular spine. Least distance between tip of anterior preopercular spine and nearest point on orbit.

18. Length of upper jaw. Greatest dimension between tip of upper jaw, at the midline, to the posterior end of the maxillary.

19. Greatest width of posterior end of maxillary.

20. Length of "schnabel". The dimension made by placing one point of the dividers or the knife-edge of a caliper on the anterior midline of the upper surface of the lower jaw between the teeth; the other divider tip or caliper edge on the most distant point of the mandibular projection or schnabel.

21. Length of longest gill raker. Distance from base of gill raker, on the side at which it forms an acute angle with the arch, to the tip of the raker.

22. Number of longest raker. The first raker which has both roots in the lower limb is counted as number one.

23. Snout to origin of dorsal fin. Anterior midpoint of tip of snout to base of first dorsal spine.

24. Snout to origin of anal fin. Anterior midpoint of snout to base of first anal spine.

25. Snout to insertion of pectoral fin. Anterior midpoint of snout to base of uppermost pectoral ray.

26. Snout to insertion of ventral fin. Anterior midpoint of snout to base of ventral spine.

27. Origin of dorsal fin to uppermost point of gill opening.

28. Origin of dorsal fin to insertion of pectoral fin. Distance from base of first dorsal spine to base of uppermost pectoral ray.

29. Origin of ventral fin to origin of anal fin. Distance between bases of ventral spine and first anal spine.

30. Posterior edge of anus to origin of anal fin (i.e. base of first anal spine).

31. Origin of anal fin to base of last dorsal ray. Distance from base of first anal spine to the rear edge of the base of the last dorsal ray.

32. Length of caudal peduncle. Distance between rear edge of base of last anal ray and the hidden base of the midcaudal ray.

33. Length of base of dorsal fin (spinous and soft). Distance between origin of first spine and rear edge of base of the last soft ray (exclusive of the membrane which connects the proximal third or quarter of this ray to the dorsal midline of the body).

34. Length of base of soft dorsal fin (including its spine). Distance from base of last spine in the dorsal fin, which is the first spine in the second dorsal fin, to the rear edge of the base of the last dorsal ray.

35. Length of base of anal fin. Distance from base of first spine to rear edge of the base of the last ray (exclusive of the membrane which follows the last ray).

36. Length of first dorsal spine.

37. Length of longest dorsal spine.

38. Number of longest dorsal spine.

39. Length of penultimate dorsal spine.

40. Length of last dorsal spine.

41. Length of longest dorsal ray.
42. Number of longest dorsal ray.
43. Length of longest ray of pectoral fin. Distance between the base and the tip of the longest ray (used in preference to a pectoral length measured from upper point of fin insertion because the pectoral length so measured varies with the position of the fin).
44. Length of ventral fin. Distance between base of ventral spine and tip of longest ray, with the fin laid back against the belly.
45. Length of ventral (fin) spine.
46. Length of first anal spine.
47. Length of second anal spine. (It is usually necessary to remove some of the skin which covers the bases of these spines.)
48. Length of third anal spine.
49. Depressed length of anal fin. Distance from base of first anal spine to the farthermost point when the fin is flattened down.
50. Dorsal fin count: e.g. XV, 13, indicating 15 spines in first dorsal and 13 rays in second or soft dorsal.
51. Anal fin count: e.g. III, 7.
52. Pectoral fin count: e.g. 4,6,9=19. 4 uppermost pectoral rays unbranched followed by 6 branched and 9 lower unbranched rays.
53. Ventral fin count: e.g. I, 5. (This count will doubtless prove to be worthless.)
54. Caudal fin count: e.g. I-11-I. Eleven branched rays flanked above and below by one long and major but unbranched ray.
55. Vertebrae count – total including hypural.
56. Precaudal vertebrae count.
57. Caudal vertebrae count – including hypural.
58. Number of gill rakers on first arch, e.g. 10+1+24. Ten on upper arch, twenty-four on the lower, and one which straddles the two.
59. Number of lateral line pores.
60. Number of scale pouches below lateral line; upper end of gill opening to base of midcaudal ray. (Remove scales with forceps or by scraping with blade.)
61. Number of scale rows between origin of anal fin and lateral line, counting upward and forward.
62. Number of scale rows around narrowest part of caudal peduncle.

Prepared by:

G. F. Kelly
G. W. Mead
U.S. Fish and Wildlife Service
March 21, 1958

APPENDIX II

Summary of Meristic Characteristics of *Sebastes* (Adult)

(From unpublished notes of Å. Vedel Tåning. Data given to senior author by the late Dr. Tåning.)

Scale pouches below lateral line

Number	*marinus*[1]	*fasciatus*[2]	Number	*viviparus*
67	–	1	49	–
66	–	1	48	–
65	–	3	47	–
64	–	4	46	–
63	1	11	45	3
62	2	11	44	9
61	3	11	43	10
60	6	13	42	20
59	5	12	41	30
58	7	14	40	31
57	6	1	39	44
56	6	1	38	31
55	7	–	37	29
54	5	–	36	25
53	1	–	35	5
52	1	–	34	1
51				a238 = 39·27
50				
	a*50 = 57·38	a83 = 60·47		

[1] *S. marinus*
[2] American form; "fasciatus" should be replaced by new name(?).
* a = average.

Number of gill rakers (Gi)

Number	*marinus*	*fasciatus*	*viviparus*
41	–	–	1
40	–	–	5
39	1	1	14
38	–	2	17
37	1	7	15
36	2	10	8
35	3	14	1
34	2	9	–
33	1	3	–
32	1	2	–
31	–	1	–
30	–	1	–
	a11 = 35·09	a50 = 35·08	a61 = 37·89

Number of rays in caudal fin

Number	*marinus*	*fasciatus*	*viviparus*
41	3		–
40	4		–
39	22		1
38	7		10
37	2		131
36	–		69
35	–		45
34	–		3
33	–		–
32	–		–
31	–		–
30	–		–
	a38 = 38·97	?	a259 = 36·40

Number of spines and rays in dorsal fin ($D_1 + D_2$)

Number	*marinus*	*fasciatus*	*viviparus*	*mentella*
31	4	1	–	–
30	17	3	3	–
29	14	27	83	–
28	3	19	165	–
27	–	–	9	–
26	–	1	–	–
	a38 = 29·58	a51 = 28·69	a260 = 28·31	
	(15 + 14 – *15*)	(15 + *13* – 14)	(15 + *13* – 14)	(15 + 14 – *15*)

Number of spines and rays in anal fin (3+x)

Number	*marinus*	*fasciatus*	*viviparus*	*mentella*
13	1	–	–	–
12	18	–	–	–
11	16	20	5	–
10	3	30	215	–
9	–	1	41	–
	a38 = 11·45	a51 = 10·37	a261 = 9·86	(3 + 8 – *9*)

Number of rays in pectoral fin

Number	*marinus*	*fasciatus*	*viviparus*	*mentella*
20	5	2	–	–
19	32	42	15	–
18	1	14	233	–
17	–	1	13	–
	a38 = 19·11	a59 = 18·76	a261 = 18·01	(18 – 19)

Total number of vertebrae

Number	*marinus*	*fasciatus*	*viviparus*	*mentella*[1]
32	1	–	–	–
31	80	9	3	10
30	16	23	116	76
29	–	–	2	3
	a97 = 30·85 (Kotthaus: 30·9)	a32 = 30·38	a121 = 30·01	a89 = 30·08

[1] *S. mentella* Travin 1951 = "Tiefenbarsch".

A/S L. Ihrich, Copenhagen

Made in United States of America
Reprinted from Journal of Mammalogy
Vol. 42, No. 2, 20 May 1961
pp. 223–234

ABUNDANCE AND DISTRIBUTION OF THE STELLER SEA LION

By Karl W. Kenyon and Dale W. Rice

Abstract: Observations of the Steller sea lion, *Eumetopias jubata,* including hauling-out habits, seasonal movements, and aerial surveys in eastern Bering Sea from Bering Strait to and including the Aleutian Islands, are presented. Sea lions haul out during winter and spring, prior to the breeding season, in greater numbers in afternoon hours than in morning hours; few haul out during storms. The dearth of animals seen in the water during aerial surveys indicates that the great majority are hauled out during fair weather in the spring. The Pribilof Islands are the northernmost breeding grounds but a number of animals, probably adult and subadult males, migrate north in late summer and early fall. As many as 1,000 regularly reach St. Lawrence Island and a few reach Bering Strait. These animals move south again with the advance of ice in the fall but ice does not cause them to desert the Pribilof Islands. Certain hauling grounds within the breeding range are used seasonally. Aerial surveys of all Aleutian Islands and areas near the end of the Alaska Peninsula in 1959 and 1960 revealed 98 rookeries and hauling grounds with an estimated total of about 100,000 animals. The total world population of this species, based on the present report and on previously published data, is estimated to be about a quarter of a million animals.

The Steller sea lion, *Eumetopias jubata,* is an abundant pinniped, primarily in neritic waters, of the temperate North Pacific Ocean. Interest in this species has been expressed because of its possible predation on commercially valuable fishes. Because of the remote and rugged habitat occupied by this sea lion and because of the difficulty of collecting specimens at sea, much is still to be learned of its habits, behavior, population dynamics, abundance and food habits. The Aleutian Islands appear to be the center of abundance of the species.

During studies of the sea otter (*Enhydra lutris*), the northern fur seal (*Callorhinus ursinus*), and the Pacific walrus (*Odobenus rosmarus divergens*), observations of the Steller sea lion were obtained. The study area includes the Aleutian Islands and eastern Bering Sea north to Bering Strait. Data were gathered on hauling-out habits, seasonal migration, and population and distribution. This paper presents results of the first complete aerial survey of the Aleutian Islands. Little information has previously been published concerning the seasonal occurrence of this species in northern Bering Sea.

METHODS

Studies of hauling-out habits were conducted by Kenyon at St. Makarius Point, Amchitka Island, during late winter and spring of 1959. A 50-power telescope and 7 × 50 binoculars were used to count sea lions on an offshore islet during varying weather conditions and at different times during the day.

Information on seasonal northward migration was obtained during pelagic sealing studies and aerial surveys and from other observers living in or visiting northern Bering Sea areas.

Aerial surveys were conducted with an R4D aircraft (a modified DC-3) equipped with two 565-liter auxiliary wing tanks, giving it a range of over 12 hours. A speed of 190 km per hour was maintained; the altitude was usually 75 m, but varied from 30 to 150 m depending on terrain and wind conditions. The flight course followed the entire shoreline of each island, from the beachline to about 100 m offshore, and circled all offshore rocks and reefs.

The location of each sea lion rookery or hauling ground was plotted on U. S. Coast and Geodetic Survey charts. As the survey was conducted prior to the breeding season, it was not possible to distinguish between rookeries and hauling grounds. The number of sea lions at each site was estimated visually by two or three observers. It was impossible to photograph each group of sea lions seen, though several groups were photographed. Counts made from the photographs closely verified the estimates that had been made during the flight (Plate 1). Although an error of from 6 to 10 per cent, similar to the results obtained by Pike and Maxwell (1958) and Bonnot and Ripley (1948), is inherent in this method, the order of magnitude of the estimates is reliable.

The western half of the Aleutian Chain, including all islands from Attu to Yunaska, was surveyed between 19 and 27 May 1959. The observers were David L. Spencer, Refuge Supervisor, Fish and Wildlife Service, and Kenyon; the pilots were Theron A. Smith, Aircraft Supervisor, Fish and Wildlife Service, and Jim Tilford, Bureau of Land Management.

The eastern Aleutians were surveyed on 3 and 4 March 1960. This flight included all islands from the Islands of Four Mountains to Unimak, and also included several islands off the west end of the Alaska Peninsula: Amak, and adjacent Sea Lion Rock; the Sanak group; and Sandman Reefs. The observers were Kenyon and Rice; the pilots were Smith and Spencer.

In addition to those mentioned above, the following individuals kindly contributed unpublished information or assisted in field work: J. W. Brooks, F. H. Fay, C. H. Fiscus, M. L. Lantis, R. L. Rausch, D. F. Riley, W. E. Ripley, J. D. Wendler, and F. Wilke.

HAULING-OUT HABITS

Any census of sea lions is best obtained when the animals are on land. Knowledge of the hauling-out habits is helpful in indicating when the most successful population surveys may be expected and in evaluating surveys after they have been made.

Between mid-February and mid-May 1959, 31 observations of a sea-lion hauling ground used by 100 to 200 sea lions of both sexes and all ages were obtained. Counts of animals on land were made at various times of day and under different weather conditions. The following general conclusions are indicated from the data:

1. During stormy weather, especially when a heavy surf was running, sea lions tended to remain in the water. The majority remained in a compact

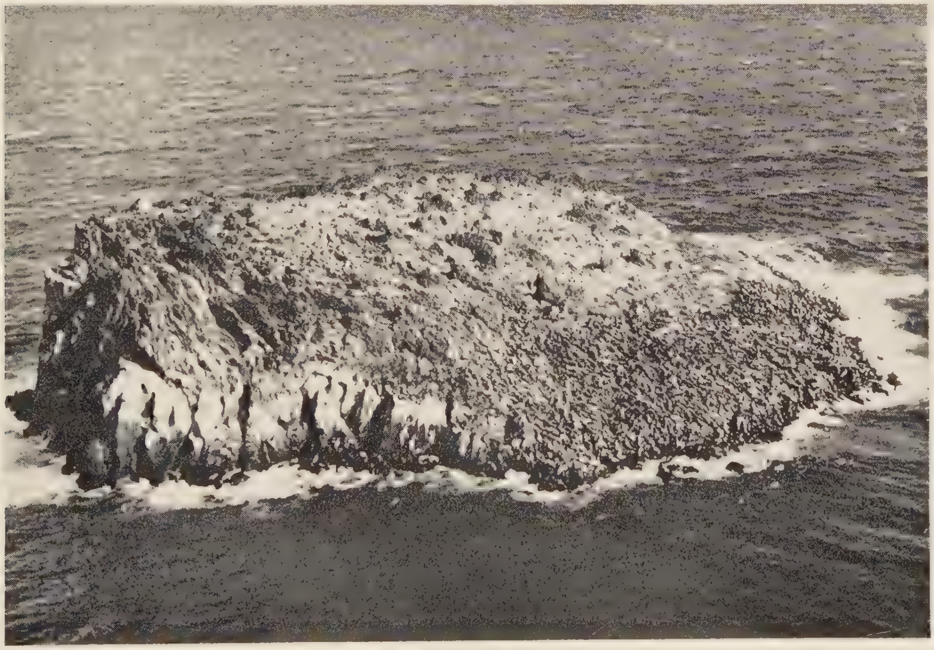


PLATE I

Sea Lion Rock, near Amak Island, Alaska. The field estimate made during a flight around this islet was 2,000 sea lions. A total of 1,905 was counted on this photograph. A few additional animals are hidden from view on the far side of the rock and others are beneath the water. 5 March 1960, KWK 60-15-3.

group in a favorite loafing area a few yards beyond the breakers near the eastern tip of the islet. Fourteen observations were made when storm conditions prevailed. During 11 of these, no sea lions were on land. In the other three instances, the numbers hauled out were 1, 2 and 36. Animals on land when a storm strikes may remain there for several hours but, as the storm progresses, they usually leave. Brooks (*in litt.*) noted, however, that on Lewis Island, where space above the beach is available, "many sea lions simply moved farther up on land during heavy weather."

2. During mild weather, especially if the wind is light and the sky clear, sea lions haul out in greatest numbers.

3. During daylight, more sea lions are on land in afternoon than in morning hours. The mean number on land during 10 morning observations was 45. The mean of 7 afternoon observations was 70. (Observations during stormy weather are excluded.) What effect tides and feeding rhythms may have on hauling-out habits was not ascertained.

MOVEMENTS

Observations in Alaska and in California indicate that the Steller sea lion undertakes seasonal movements, both latitudinal and local or longitudinal. Available data give a general indication of such movements but much is yet to be learned concerning the seasonal movements of different sex and age classes. Seasonal migration in the most northern part of the species' range appears to differ from that in extreme southern areas.

Latitudinal seasonal movement of the Steller sea lion is evident at the northern and southern extremities of the species' range. Bonnot (1951: 377) noted that "very few Steller bulls can be found on the California coast during winter." Bartholomew and Boolootian (1960) found no adult males in winter or spring in the California Channel Islands but found them there in June, indicating a northward movement of males during winter and spring. In the Bering Sea, northward movement takes place in the summer.

During low-altitude aerial surveys of St. Lawrence, St. Matthew, Hall, Nunivak, and the Walrus Islands of northern Bristol Bay in late February and early March 1960, no sea lions were seen. Surveys of the same areas again in late April revealed sea lions only on The Twins of the Walrus Islands where 400 were seen on 27 April (Wendler, *in litt.*). In late June of 1958, 66 sea lions, mostly subadults and a few adult males, were counted on The Twins (Fiscus, *in litt.*), perhaps indicating that many of those which arrive in the spring continue northward movement as the ice retreats.

Several hundred sea lions occupy St. Matthew and Hall islands in the summer. They apparently do not arrive, however, until after mid-July. Hanna (1920) spent 8 to 14 July 1916 there and did not record the species. On 9 August 1957, Klein (1959 and *in litt.*) saw 350 sea lions hauled out about 2 miles south of Elephant Rock on Hall Island. No pups were present; all animals were adult or subadult. Three carcasses found on beaches of St. Matthew were males. On 2 August 1960, over 100 sea lions were hauled out at the base of Cape Upright, St. Matthew Island (Wilke and Fiscus, *in litt.*).

At St. Lawrence Island, sea lions occur regularly but in variable numbers in summer and early fall. Fay (*in litt.*) gives the following information from field notes taken 1953 through the fall of 1959: "The principal places occupied are the offshore rocks at Southwest Cape ("Pikaluk"), 63° 18′ N, 171° 27′ W, and the southernmost of the Punuk Islands, 63° 04′ N, 168° 50′ W." None has been recorded prior to 27 June. From late June until late September, individuals and groups of five or six animals were seen but their presence during this period varied in different years. On 25 September 1953, about 1,000 were on the rocks and beach at Southwest Cape and 3 or 4 days later 200 were on south Punuk Island. The natives say that the greatest number arrives in September and that they depart in November when the ice comes. The animals are molting when they haul out at St. Lawrence. Each year the natives take about 20 animals. No females have been taken and it is presumed that all sea lions seen there were males.

In the course of anthropological studies on Nunivak, Lantis questioned resident Eskimos in detail about marine mammals. Of the sea lion, she says (*in litt.*), ". . . an old Nunivaker, a man who had been an oustanding hunter, told me in 1940 that they were found on the west side of the island. They were harpooned in spring and summer, especially in summer, in open water. . . . Although not numerous they were known to all hunters." Spencer, who has conducted aerial surveys of Nunivak, says (*in litt.*), "I have no record of sea lions on Nunivak Island. Our surveys have all been conducted in winter or June and early July."

Natives of Little Diomede told Kenyon that a few individual sea lions are seen, especially near Fairway Rock and the south end of Big Diomede, in late summer and early fall; but their occurrence is not regular and they leave as soon as the ice comes. Rarely is an animal taken.

It may be assumed that the sea lions which migrate to the northern Bering Sea in summer move north from as far south as the Aleutian Islands. In June and July of 1955, during pelagic fur-seal studies between Unimak Pass and the Pribilof Islands, Kenyon saw several individual adult male sea lions, far at sea, swimming steadily in a northerly direction. During a pelagic sealing cruise from Amak Island to the Pribilofs on 11 and 12 July 1960, Fiscus and Kenyon saw a total of 12 sea lions well away from land. A group of eight adult and subadult males were 70 nautical miles north of Unimak Island and two others were 85 miles east of St. George. Tagging programs now being undertaken by both the Alaska Department of Fish and Game and the U. S. Fish and Wildlife Service should eventually contribute much information on the movements of sea lions.

Within its latitudinal range of year-round abundance, from the Pribilof Islands to central California, local seasonal or longitudinal movements of variable degree occur. In general, it appears that breeding grounds are also used

TABLE 1.—*Steller sea lion populations in the Aleutian Islands*

Reference number	Location of hauling ground or rookery	Estimated number of sea lions
	Near Islands:	
1	Attu (Cape Wrangell)	5,000
2	" (Chirikof Point)	10
3	Agattu (Gillan Point)	3,000
4	" (Otkriti Bay)	100
5	" (Cape Sabak)	3,300
6	Alaid (west end)	1,500
7	Shemya (rocks off north shore)	2,500
	Rat Islands:	
8	Buldir (south shore)	2,500
9	Kiska (Cape St. Stephen)	1,000
10	" (Vega Point)	400
11	Tanadak	50
12	Rat Island (eastern point)	750
13	Amchitka (Bird Rock)	50
14	" (islet off Chitka Point)	50
15	" (Ivakin Point)	300
16	" (East Cape)	200
17	" (St. Makarius Islet)	50
18	" (southwest islets and rocks)	600
19	Semisopochnoi (rocks off SW shore)	500
20	" (Pochnoi Point)	2,000
	Delarof Islands:	
21	Amatignak (Nitrof Point)	200
22	" (Knob Point)	50
23	Unalga (Dinkum Rocks)	350
24	Ulak (south point)	1,500
25	Gareloi (south shore)	2,500
26	Skagul (rocks off south point)	500
27	Tag Island	400
28	Ugidak	400
29	Gramp Rock	700
	Andreanof Islands:	
30	Tanaga (Sasmik Cape)	75
31	" (north side of Cape Sajaka)	100
32	Adak (Argonne Point)	1,000
33	" (Hook Point)	1,500
34	" (Cape Yakak)	800
35	" (rock off Cape Moffett)	50
36	Little Tanaga (Tana Point)	450
37	Great Sitkin (Swallow Head)	650
38	Anagaksik	700
39	Igitkin (southwest point)	700
40	Kasatochi (north point)	200
41	Ikiginak	500
42	Atka (North Cape)	550
43	" (Cape Korovin)	100
44	Salt Island	100
45	Sagchudak	1,200

TABLE 1 (contd.).—*Steller sea lion populations in the Aleutian Islands*

Reference number	Location of hauling ground or rookery	Estimated number of sea lions
46	Amtagis	800
47	Amlia (Cape Misty)	750
48	″ (rocks in Sviechnikof Harbor)	800
49	″ (Agligadak Point)	700
50	Sagigik	100
51	Tanadak	20
52	Agligadak	250
53	Seguam (southwest point)	150
54	″ (Lava Point)	150
55	″ (Wharf Point)	100
56	″ (Saddle Ridge Point)	25
57	Amukta (High Rock and adjacent rocks)	600
58	″ (Amukta Point)	150
59	Chagulak (Chagulak Point)	100
60	Yunaska (east shore)	800
	Islands of Four Mountains:	
61	Carlisle Island (northwest point)	100
62	Chuginadak (Concord Point)	700
63	Uliaga (northwest shore)	500
64	Kagamil (north point)	75
	Fox Islands:	
65	Adugak	1,000
66	Ogchul	2,000
67	Umnak (Cape Aslik)	450
68	″ (Cape Idak)	600
69	Unalaska (Point Tebenkof)	200
70	″ (Cape Starichkof)	100
71	″ (Spray Cape)	200
72	″ (Cape Izigan)	150
73	″ (Whalebone Cape)	1,000
74	″ (Cape Kalekta)	10
75	Bogoslof	1,000
76	Fire Island	100
77	Akutan (Lava Point)	6,520
78	″ (between Lava Bight and Reef Bight)	200
79	″ (Flat Bight)	2,000
80	″ (Cape Morgan)	7,000
81	Akun (Akun Head)	2,000
82	″ (Billing's Head)	100
83	Tanginak	600
84	Tigalda (rock off west end)	10
85	″ (rock off northeast end)	750
86	Ugamak (west end)	400
87	″ (southeast point)	1,500
88	″ (northeast point)	10,000
89	″ (north point)	1,000
90	″ (northwest point)	500
91	Aiktak	600
92	Round Island	6,000

TABLE 1 (contd.).—*Steller sea lion populations in the Aleutian Islands*

Reference number	Location of hauling ground or rookery	Estimated number of sea lions
93	Unimak (Oksenof Point)	4,000
94	" (Cape Sarichef)	200
	Amak group:	
95	Amak	350
96	Sea Lion Rock	2,000
	Sanak group:	
97	South Rock	1,000
	Sandman Reefs:	
98	Clubbing Rocks	200
Total on land		99,745
Total in water		460
Grand total		100,205

as hauling grounds at all seasons but some hauling grounds are used only at certain seasons. During the breeding season, nonbreeders may occupy areas not used during winter months. An example is a small islet in Kirilof Bay at Amchitka Island. Several hundred nonbreeding adult and subadult animals habitually haul out on this islet during summer and early fall. In late fall it is deserted and during winter and early spring none has been seen there. A reversal of seasonal occupancy is observed at Otter Island of the Pribilofs. During summer months only 75 to 160 adult and subadult males are scattered along its rocky beaches but local residents say that during winter months large numbers regularly haul out and occupy an area of gently sloping land away from the beach on the north side of the island.

Although the Steller sea lion is not an ice animal and deserts its northernmost hauling grounds as the ice advances in late fall, ice does not cause sea lions to desert the Pribilof Islands. On 9 April 1955, when pack ice surrounded the Pribilofs, Wilke and Kenyon saw approximately 1,000 sea lions hauled out on Otter Island and several others rested on ice floes. The few animals that could be identified as to sex were males, perhaps indicating a southward winter movement of adult females in this northernmost breeding area.

AERIAL SURVEYS

From the above discussion it is evident that the winter-spring aerial surveys of the Aleutian Islands took place during the period when a maximum number of sea lions might be expected in that area. Since some areas were surveyed during morning hours, it is indicated that the total estimates of animals seen on land are lower than they would have been if all surveys could have been conducted during afternoon hours. All surveys were conducted during fair weather. Unknown numbers of animals are in the water at all times and are not seen. On the basis of the few (460) seen in the water at distances from hauling-out areas, however, it may be assumed that a large majority were hauled out. A complete list of the locations and estimated numbers of sea lions seen are shown in Table 1 and the geographical location of each group is indicated on Fig. 1. It is interesting to note that aerial surveys of sea lions conducted by the Fisheries Research Institute (Mathisen, 1959), which made extensive use of aerial photography, correspond closely with the estimates we obtained in areas where the surveys overlapped.

DISCUSSION

The breeding range of the Steller sea lion extends from Santa Rosa Island off southern California (34° N; Bonnot, 1929) to the Pribilof Islands (57° 15′ N). In summer and fall a northward movement of animals, apparently all males, as far as Bering Strait (65° 45′ N) occurs. An individual (identity not verified) recorded at Herschel Island, Yukon Territory (69° N; McEwen, 1954) was a wanderer far north and east of the regular summer range.

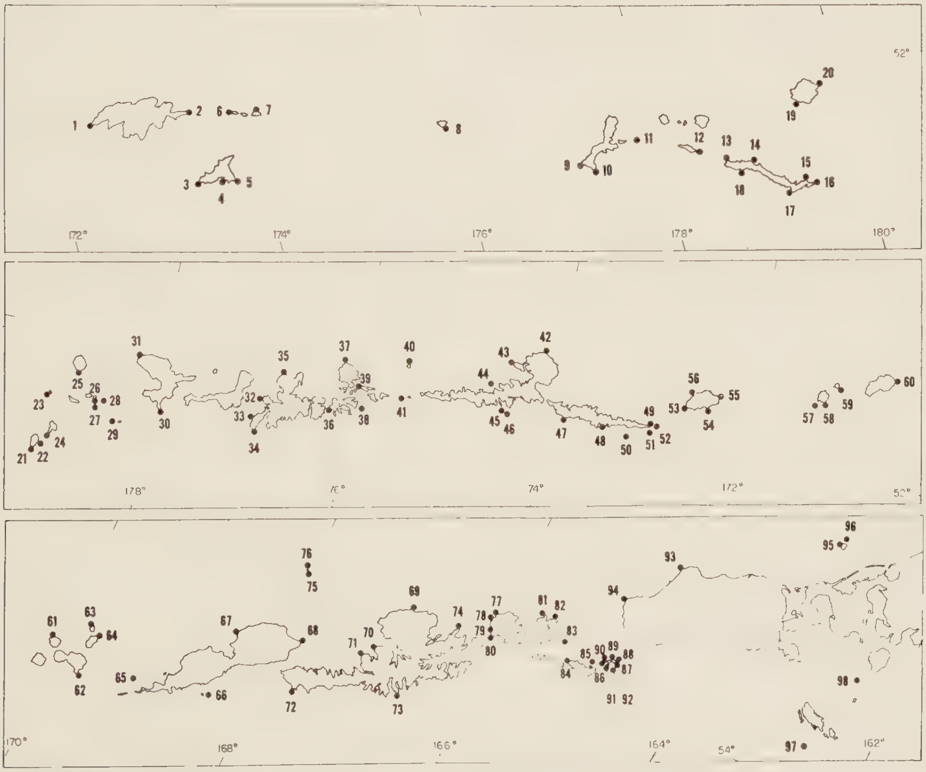

52°
20
19
1
2
6
7
8
9
10
11
12
13
14
15
16
17
18
3
4
5
172°
174°
176°
178°
180°
31
35
37
40
42
43
44
56
60
21
22
23
24
25
26
27
28
29
30
32
33
34
36
38
39
41
45
46
47
48
49
50
51
52
53
54
55
57
58
59
178°
176°
174°
172°
52°
96
95
76
75
93
69
94
61
62
63
64
65
66
67
68
70
71
72
73
74
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
98
97
170°
168°
166°
164°
54°
162°

Fig. 1.—Map of the Aleutian Islands, showing location of Steller sea lion rookeries and hauling grounds in use at the time of the surveys. Upper: Near Islands to Rat Islands; middle: Delarof Islands to Yunaska; lower: Islands of Four Mountains to Alaska Peninsula. For key, see Table 1.

It does not breed on the Commander Islands, but from October to April, "sea lions, almost exclusively males" are found there. At the beginning of April they probably migrate to the east coast of Kamchatka (Barabash-Nikiforov, 1938). The species has also been recorded from Hokkaido, northern Hondo, and Korea (Ellerman and Morrison-Scott, 1951; Okada, 1938). Nishiwaki and Nagasaki (1960) estimate that 1,000 to 3,000 Steller sea lions migrate to the coastal waters of Japan. Aside from a report of about 35 sea lions on Todo-iwa on the Hidaka coast of Hokkaido, which were attacked with aircraft at the request of local fishermen on 26 March 1959 (American Embassy, Tokyo, Foreign Service Dispatch No. 1135, 3 April 1959), no recent specific information on sea lions in this area seems to have been published. During fur-seal studies in waters near Hokkaido in the winter, spring, and summer of 1949, 1950 and 1952, Wilke and Kenyon saw no Steller sea lions.

A résumé of published information concerning population estimates of Steller sea lions throughout their range is presented in Table 2. Most of the authorities cited also give precise locations for each rookery or hauling ground within their

TABLE 2.—*Summary of population estimates of Steller sea lions*

Area	Number	Authority
Southern California	50	Bartholomew and Boolootian (1960)
Northern California	6,002	California Department of Fish & Game (*in litt.*, 1960)*
Oregon	650– 1,000	Rice, Field notes, 1960
Washington	400– 500	Kenyon and Scheffer (1959)
British Columbia	11,000– 12,000	Pike and Maxwell (1958)
Southeastern Alaska to the Shumagin Islands	76,027	Mathisen (1959)
Aleutian Islands	100,205	Present report
Pribilof Islands:		
St. Paul Island and Sea Lion Rock	300	Kenyon, field notes, 1960
Otter Island	160	Kenyon, field notes, 1960
Walrus Island	4,000– 5,000	Kenyon, field notes, 1960
St. George Island	1,200	Riley, field notes, 1960
Kamchatka (9 rookeries and hauling grounds)	No data	Rass *et al.* (1955)
Kurile Islands (23 rookeries and hauling grounds)	15,000– 17,000	Klumov (1957)
Okhotsk Sea (Svyatov Iony)	5,000– 6,000	Nikulin (1937)
Okhotsk Sea (9 other rookeries and hauling grounds)	No data	Rass *et al.* (1955)
Total	219,914–225,444	

* Ripley gives the following information: "We have made aerial estimates of sea lions on rookeries of California for the years 1958 and 1960. Although we do not have the species delineated in the aerial photos, it can be considered that the population north of Point Conception is nearly all Stellers. Therefore, based on this assumption, the counts for 1958 would be 7,116 and for 1960 would be 6,002. Our estimates this year did not include Southern California or the California islands."

respective areas. Therefore, it appears that a large majority of the rookeries and hauling grounds used by this species have been recorded. Omitted from this summary are the several hauling grounds in the Bering Sea north of the Pribilof Islands; census figures from rookeries and hauling grounds only within the year-round range of the species are used to avoid possible duplication.

The total estimates range from 220,000 to 225,000. There are no data available for nine rookeries and hauling grounds on the east coast of Kamchatka, and nine in the Okhotsk Sea and on Sakhalin, as reported by Rass *et al.* (1955). In the Kurile Islands, the mean number of animals hauled out on each rookery or hauling ground is about 700. A tentative guess of 13,000 animals on the 18 sites for which no counts are available may thus be made, giving a total estimate of about 233,000 to 238,000 on recorded rookeries and hauling grounds. It is, of course, impossible to estimate the number of animals missed in the surveys because they were in the water. It is the opinion of the authors that the total Steller sea-lion population numbers between 240,000 and 300,000.

LITERATURE CITED

Barabash-Nikiforov, I. I. 1938. Mammals of the Commander Islands and the surrounding sea. J. Mamm., 19: 423–429.

Bartholomew, G. A. and R. A. Boolootian. 1960. Numbers and population structure of the pinnipeds on the California Channel Islands. J. Mamm., 41: 366–375.

Bonnot, P. 1929. Report on the seals and sea lions of California, 1928. Calif. Div. Fish and Game, Fish Bull. 14, 62 pp.

————. 1951. The sea lions, seals and sea otter of the California coast. Calif. Fish and Game, 37: 371–389.

Bonnot, P. and E. Ripley. 1948. The California sea lion census for 1947. Calif. Fish and Game, 34: 89–92.

Ellerman, J. R. and T. C. S. Morrison-Scott. 1951. Checklist of Palaearctic and Indian Mammals, 1758 to 1946. London, Brit. Mus. (Nat. Hist.), 810 pp.

Hanna, G. D. 1920. Mammals of the St. Matthew Islands, Bering Sea. J. Mamm., 1: 118–122.

Kenyon, K. W. and V. B. Scheffer. 1959. Wildlife survey of islands off the northwest coast of Washington, 13–17 July 1959. Unpublished report in Fish and Wildlife Service files.

Klein, D. R. 1959. Saint Matthew Island reindeer-range study. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Wildl. No. 43, 48 pp.

Klumov, S. K. 1957. [Registration of the shore rookeries of sea lions (*Eumetopias jubatus*) in the Kurile Islands and tentative determination of their numerical magnitude.] Rept. Acad. Sci. USSR. 117: 345–348. (In Russian.)

McEwen, E. H. 1954. A sporadic occurrence of an Alaskan fur seal. J. Mamm., 35: 444.

Mathisen, O. A. 1959. Studies on Steller sea lion (*Eumetopias jubata*) in Alaska. Trans. N. Amer. Wildl. Conf., 24: 346–356.

Nikulin, P. G. 1937. [Sea-lions of the Okhotsk Sea and their exploitation.] Bull. Pacif. Sci. Inst. Fish. Oceanogr., Vladivostock, 10: 35–48. (In Russian, with English summary.)

Nishiwaki, M. and F. Nagasaki. 1960. Seals of the Japanese coastal waters. Mammalia, 24: 459–467.

Okada, Y. 1938. A catalogue of vertebrates of Japan. Tokyo, Maruzen, 4 + 412 pp. (In English and Japanese.)

PIKE, G. C. AND B. E. MAXWELL. 1958. The abundance and distribution of the northern sea lion (*Eumetopias jubata*) on the coast of British Columbia. J. Fish. Res. Bd. Canada, 15: 5–17.

RASS, T. S., A. G. KAGANOVSKIY AND S. K. KLUMOV, editors. 1955. [Pinnipedia, sect. 4, p. 95–115.] *In* [Geographical distribution of fishes and other commercial animals.] Trudy Instituta Okeanologii, Tom 14, pp. 1–120. (In Russian.)

U. S. Fish and Wildlife Service, Sand Point Naval Air Station, Seattle 15, Washington.
Received 14 November 1960.

Comparison of Three Tags on Striped Bass in the Chesapeake Bay Area[1]

Robert M. Lewis

ABSTRACT

Petersen disk, nylon streamer, and jaw ring tags were applied to striped bass, *Roccus saxatilis*, in the Chesapeake Bay area in 1957. The primary objective was to determine the tag most suitable for a study of movement and in estimating population size. Tag return data were analyzed statistically to test comparative merits of tags. Petersen disk tags were returned selectively from gillnets in some size classes of fish as compared to nylon streamer and jaw ring tags. There was little difference in the suitability of jaw ring and streamer tags to requirements of the study. The streamer tag was chosen only because it was easier to obtain than the jaw ring tag.

Prior to beginning the tagging study of striped bass, *Roccus saxatilis* (Walbaum), in Chesapeake Bay, it was recognized that estimates of abundance, mortality, and movement would be largely dependent upon the adequacy of the tag employed. One of the principal objectives of tagging during the first year of study was the selection of a tag that was durable and would neither tangle in gear nor hamper the activity of fish.

The practicability of using a variety of tag types on striped bass has been investigated by others. Davis (1959:319–29) reported on tests of Petersen, streamer, and spaghetti tags on striped bass in North Carolina. His results indicated that streamer tags were most suitable for studies of populations and fish movement in that area. Vladykov (1957:345–9) first described tests with the jaw ring (split ring and plate) tag. Calhoun (1953:209–18) reported that the Petersen disk tag placed under the first dorsal fin seemed the most satisfactory in aquarium tests of four tags in four body locations. A review of these findings indicated that at least one of the above tag types would probably satisfy requirements on striped bass research in Chesapeake Bay but did not resolve the choice among cooperating investigators. For this reason Petersen, nylon streamer, and jaw ring tags were tested so that one could be selected which would most nearly meet all requirements of the study.

Tests of tag types were made possible by the cooperation of the following individuals: William H. Massmann and Anthony L. Pacheco[2], Virginia Fisheries Laboratory; Edgar H. Hollis, Maryland Department of Tidewater Fisheries; and Romeo J. Mansueti, Maryland Department of Research and Education. These individuals and their colleagues were responsible for a large portion of the field work and resulting tag-return data analyzed in this paper.

Materials and Methods

Petersen disk, nylon streamer, and jaw ring tags were applied to striped bass caught by haul seine, pound net, drift and stake gillnets, otter trawl, and hook and line. Fish were weighed, measured to fork length (F.L.), tagged, and released in the area of capture. When applying two or more types of tags for testing purposes, an attempt was made to use them in equal numbers for each 1-inch increment of fish length. Scale samples were taken for age and growth determination.

Tags:—The Petersen tag consisted of two red plastic disks $\frac{7}{16}$-inch in diameter. One disk was blank and the other bore a code number on one side, with the return address and $1.00 reward notice on the other side. The tag was attached by inserting a stainless steel pin through the back of the fish under the first dorsal fin.

---

[1] Contribution No. 174, Maryland Department of Research and Education, Solomons, Maryland.

[2] Presently with the U. S. Bureau of Commercial Fisheries.

The streamer tag consisted of a numbered Petersen disk attached to the fish with a 7-inch loop of nylon net-twine. The loop was threaded through the back of the fish under the second dorsal fin with a 7-inch upholsterer's needle having a notched eye. The tag was then tied so that the disk trailed over the caudal peduncle.

The jaw ring tag consisted of a Petersen disk attached to either a ¾-inch or 1-inch diameter stainless steel ring which was clamped around the mandible with pliers. The size of the fish determined the diameter of the ring.

Tagging:—Petersen disk and nylon streamer tags were tested by biologists of Virginia Fisheries Laboratory and the U. S. Bureau of Commercial Fisheries. During 11 engagements, 1,422 striped bass were tagged and released in the James, York, and Rappahannock Rivers during February, March, and April 1957 (Table 1). Of these, 98 percent were taken from haul seines and 1 percent each from stake gillnets and an otter trawl. Fifty-three percent of the haul seine fish were tagged with Petersen disk tags and 47 percent with nylon streamer tags. In the Rappahannock and James Rivers, equal numbers of fish were tagged with Petersen and streamer tags. An effort was made to apply equal numbers of the two types of tags each trip in the York River, but this was not always possible.

TABLE 1.—Numbers of Petersen and streamer tags applied to striped bass, *Roccus saxatilis*, in the James, York, and Rappahannock Rivers, 1957, by Virginia Fisheries Laboratory, and number of returns by gear type.

Size classes (inches fork length)	Petersen tags			Streamer tags		
	Tags applied	Tag returns		Tags applied	Tag returns	
		Selective gear[1]	Nonselective gear[2]		Selective gear[1]	Nonselective gear[2]
7	1	—	—	3	—	—
8	12	2	2	19	—	—
9	65	5	5	75	—	1
10	144	23	24	124	5	19
11	116	21	16	95	2	12
12	94	28	11	106	4	8
13	52	22	4	57	3	5
14	52	14	1	47	3	2
15	61	17	5	51	6	1
16	39	12	—	37	2	3
17	21	8	1	12	6	1
18	20	8	—	8	2	-
19	6	3	—	2	—	—
20	71	17	11	32	1	5
Total	754	180	80	668	34	57

[1] Gillnet.

[2] Pound net, haul seine, fyke net, hook and line.

TABLE 2.—Numbers of Petersen and streamer tags applied to striped bass, *Roccus saxatilis*, in the Potomac River, upper Chesapeake Bay, and Chesapeake and Delaware Canal, 1957, by Maryland Department of Research and Education, and number of returns by gear type.

Size classes (inches fork length)	Petersen tags			Streamer tags		
	Tags applied	Tag returns		Tags applied	Tag returns	
		Selective gear[1]	Nonselective gear[2]		Selective gear[1]	Nonselective gear[2]
≤9	8	5	1	3	—	—
10	35	15	4	32	2	2
11	74	45	8	77	15	1
12	79	33	5	78	25	10
13	63	36	3	63	21	7
14	67	26	3	59	16	5
15	44	16	4	42	9	3
16	40	17	3	37	9	1
17	19	9	2	18	8	2
≥18	11	3	2	10	2	1
Total	440	205	35	419	107	32

[1] Gillnet.

[2] Pound net, haul seine, fyke net, hook and line.

Biologists of the Maryland Department of Research and Education tested Petersen and streamer tags on striped bass from March through June 1957 in the upper Bay, the Potomac River, and the Chesapeake and Delaware Canal. During 22 engagements, 859 striped bass were tagged (Table 2). Eighty-four percent were from stake gillnets, 11 percent from drift gillnets, and 5 percent from hook and line.

Biologists of the Maryland Department of Tidewater Fisheries tested Petersen, streamer, and jaw ring tags on striped bass in the upper Bay and in the Chesapeake and Delaware Canal from February through November 1957. Two thousand forty-eight fish

TABLE 3—Numbers of Petersen, streamer, and jaw ring tags applied to striped bass, *Roccus saxatilis*, in upper Chesapeake Bay and Chesapeake and Delaware Canal, 1957, by Maryland Department of Tidewater Fisheries, and number of returns by gear type.

Size classes (inches fork length)	Petersen tags			Streamer tags			Jaw ring tags		
	Tags applied	Tag returns		Tags applied	Tag returns		Tags applied	Tag returns	
		Selective gear[1]	Non-selective gear[2]		Selective gear[1]	Non-selective gear[2]		Selective gear[1]	Non-selective gear[2]
7	13	7	—	12	—	3	13	—	1
8	90	54	4	76	1	8	96	—	21
9	118	68	8	117	4	12	119	2	21
10	146	55	9	153	5	11	157	2	20
11	103	32	10	110	6	9	111	10	7
12	80	22	13	70	10	3	67	8	8
13	37	11	5	31	6	2	39	4	1
14	24	5	7	17	—	4	29	6	8
15	23	11	3	22	4	5	24	7	1
16	23	13	2	22	2	2	19	5	1
17	19	5	2	17	2	2	16	3	2
18	5	4	—	3	—	—	3	—	—
19	—	—	—	1	1	—	1	—	—
20	15	3	—	4	2	—	3	1	—
Total	696	290	63	655	43	61	697	48	91

[1] Gillnets.

[2] Pound net, haul seine, fyke net, hook and line.

were tagged during 27 engagements (Table 3). Sixty percent were from pound nets, 26 percent from haul seines, and 14 percent from drift gillnets.

Tag recovery:—Several methods were used to recover tags. Letters explaining the tagging program were sent to all licensed commercial fishermen, and biologists contacted the fishermen to collect tags. Letters and newspaper articles were employed in areas where sport and commercial fishermen were concentrated. When a tag was returned by mail with insufficient details regarding recapture, a card was sent to the fisherman requesting that the omitted items be completed.

Treatment of Tag Recovery Data:—Returns were classified by each cooperating agency as: (1) tags from selective gear (gillnet) which by mesh dimension determines the size range of fish captured; and (2) tags from non-selective gear (pound net, haul seine, fyke net, hook and line) which retains fish of all sizes. Of 1,384 recovered tags, 58 could not be classified by recovery gear or date of recapture and consequently were not used in analyses. Chi-square tests were employed in evaluating tag returns by gear, tag type, and size of fish. These tests were made separately for returns of tags applied by the three agencies.

Results

ANALYSIS OF TAG RETURNS

Results of chi-square tests based on returns from tags applied in the James, York, and Rappahannock Rivers by Virginia Fisheries Laboratory showed that: (1) in selective gear there was a significantly greater number of Petersen disk tags returned than nylon streamer tags among size classes of fish less than 17 inches F.L.; (2) in selective gear there was no significant difference between the number of returns of Petersen disk tags and nylon streamer tags for fish 17 inches or more in length (Table 4a); and (3) there was no significant difference in the number of Petersen disks and nylon streamer tags returned from non-selective gear for any of the size classifications (Table 4d).

Tag returns were compared from striped

TABLE 4.—Chi-square values in comparing returns of Petersen and streamer tags applied to striped bass, *Roccus saxatilis*, in the Chesapeake Bay area.

Laboratory and location of tagging	Size classes (inches-fork length)					
	≥ 12	≥ 13	≥ 14	≥ 15	≥ 16	≥ 17
Recaptured in selective gear						
a. Virginia Fisheries Laboratory (James, York, and Rappahannock Rivers)	62.73	38.33	21.84	14.57	9.86	2.99
b. Maryland Department of Research and Education (Potomac River, upper Bay, and Chesapeake and Delaware Canal)	12.76	11.55	5.76	3.83	1.69	0.004
c. Maryland Department of Tidewater Fisheries (upper Bay and Chesapeake and Delaware Canal)	17.58	13.86	13.91	11.31	7.15	0.44
Recaptured in non-selective gear						
d. Virginia Fisheries Laboratory (James, York, and Rappahannock Rivers)	0.09	0.04	0.003	0.004	0.72	0.21
e. Maryland Department of Research and Education (Potomac River, upper Bay and Chesapeake and Delaware Canal)	1.14	0.14	0.001	0.36	0.25	0.01
f. Maryland Department of Tidewater Fisheries (upper Bay and Chesapeake and Delaware Canal)	1.57	0.02	0.06	0.50	0.001	0.004

$\chi^2 = 3.84$ at the 5 percent level of significance.

bass tagged by the Maryland Department of Research and Education in the Potomac River, upper Bay, and Chesapeake and Delaware Canal. Tests between returns of Petersen and nylon streamer tags in selective gear produced the following results: (1) significantly greater numbers of Petersen tags were recovered from fish less than 15 inches F.L. than streamer tags; and (2) no significant difference was found between the number of recoveries of tags from fish equal to or greater than 15 inches F.L. (Table 4b). There was no significant difference between the number of recoveries from non-selective gear for any size group of fish (Table 4e).

Comparisons were made between returns of Petersen disk and nylon streamer tags on fish tagged in the upper Bay and the Chesapeake and Delaware Canal by the Maryland Department of Tidewater Fisheries. The following results occurred for returns in selective gear: (1) significantly greater numbers of Petersen tags were recovered from fish less than 17 inches F.L. than streamer tags; and (2) no significant difference occurred between the number of recoveries from fish equal to or greater than 17 inches F.L. (Table 4c). There was no significant difference between the number of recoveries in non-selective gear for any size group of fish (Table 4f).

Comparisons were also made between Petersen disk and jaw ring tags and between jaw ring and streamer tags from the returns of tags applied to fish in the upper Bay and Chesapeake and Delaware Canal (Table 5). When comparing returns of Petersen disks with those of jaw ring tags from selective gear, the following results occurred: (1) significantly greater numbers of Petersen tags were recovered from fish less than 16 inches F.L. than were jaw ring tags; and (2) there was no significant difference between the

TABLE 5.—Chi-square values in comparing returns of tags applied to striped bass, *Roccus saxatilis*, in the upper Chesapeake Bay region by Maryland Department of Tidewater Fisheries.

Tag types	Size classes (inches-fork length)					
	≥ 12	≥ 13	≥ 14	≥ 15	≥ 16	≥ 17
Recaptured in selective gear						
Petersen versus jaw ring	13.28	8.35	4.32	4.62	3.25	0.74
Streamer versus jaw ring	0.28	0.73	2.60	0.98	0.28	0.02
Recaptured in non-selective gear						
Petersen versus jaw ring	1.03	0.46	0.03	0.04	0.07	0.00
Streamer versus jaw ring	0.01	0.34	0.07	1.17	1.02	0.19

$\chi^2 = 3.84$ at the 5 percent level of significance.

number of recoveries of tags from fish equal to or greater than 16 inches F.L. There was no significant difference between the number of recoveries from these two tag types from non-selective gear for any size groups of fish. When comparing jaw ring tag returns to those of streamer tags, there was no significant difference in selective or non-selective gear between the number of returns for any of the size classes of fish tested.

A variation in the point of significance by size classes of fish occurred in those tagged by the Maryland Department of Research and Education and the other two agencies when comparing Petersen and streamer tags in selective gear. In these fish (Table 4b) the difference in return of the two tags was non-significant among size classes equal to and greater than 15 inches, and in those tagged by the other two agencies the difference was non-significant among size classes equal to and greater than 17 inches (Tables 4a, b). The difference was non-significant in fish equal to or greater than 16 inches in comparing Petersen and jaw ring tabs in selective gear (Table 5). It is not definitely known why the point of separation was different in the above instances; however, a variation in mesh size by area of recapture is probably responsible.

Condition and Durability of Recovered Tags

The majority of tags were returned within a few months after being released and were clean and legible. In the spring of 1959, a marine growth was observed on a few streamer tags which were attached more than one year prior to recapture. Infected tagging wounds were rare except in the small number of fish bearing tags on which a growth occurred.

Identical plastic was used in the manufacture of all three types of tags, but the jaw ring tags which were out more than a year had a tendency to become cracked and worn. The Petersen and streamer tags did not exhibit this characteristic. It appears that the method of attachment may have resulted in different conditions occurring in the tags. The Petersen tag was held firmly to the sides of the fish and the streamer tag trailed over the caudal peduncle. The jaw ring tag was attached to the side of the jaw and gave the plastic disk more opportunity to rotate, wear, and be lost from the ring.

Table 6.—Numbers of Petersen, streamer, and jaw ring tags applied to striped bass, *Roccus saxatilis*, concurrently by the Maryland Department of Tidewater Fisheries and number of returns by tag type and by time interval [Percentage of recoveries in parentheses].

Tag Type	Number applied during spring	Days free						
		0–7	8–28	29–49	50–70	71–91	92–450	≥451
Petersen	308	19 (6.2)	9 (2.9)	17 (5.5)	5 (1.6)	12 (3.9)	54 (17.5)	— (—)
Streamer	293	9 (3.1)	4 (1.4)	9 (3.1)	4 (1.4)	6 (2.0)	12 (4.1)	— (—)
Jaw ring	306	11 (3.6)	5 (1.6)	5 (1.6)	4 (1.3)	3 (1.0)	17 (5.6)	1 (0.3)
	Number applied during fall							
Petersen	376	3 (0.8)	28 (7.4)	10 (2.6)	21 (5.6)	55 (14.6)	114 (30.3)	5 (1.3)
Streamer	342	4 (1.2)	12 (3.5)	1 (0.3)	3 (0.9)	2 (0.6)	46 (13.4)	5 (1.4)
Jaw ring	455	7 (1.5)	23 (5.0)	1 (0.2)	2 (0.4)	4 (0.9)	65 (14.2)	13 (2.8)

An accurate comparison of tag types recovered by time interval could be made only when the three types were used simultaneously in one fishing season. For instance, fish tagged with streamer tags in February could not be compared with those tagged with jaw rings in May because the former would be subjected to the spring fishery immediately, whereas the latter tagged at the end of spring fishing would not be subject to recapture until at least the following fall. The length of time between tagging and recapture of the jaw ring tag in this instance would appear to be much greater than that of the Petersen tag. The Maryland Department of Tidewater Fisheries was the only cooperator applying enough rings concurrently with the other two types to make this comparison possible. The data from that agency were available from both spring and fall tagging in 1957 and were used in comparing length of time free by tag type (Table 6). The percentage of return for the Petersen tag was higher than for the other two tags except in two instances, (0–7 and ≥ 451 day intervals) in the fall tagging. Examination of streamer and jaw ring tag returns by the chi-square method showed no significant difference between tag-recapture interval by tag type.

Conclusions

Statistical comparison of Petersen, streamer, and jaw ring tag returns showed that Petersen tag returns were significantly greater in selective gear than streamer and jaw ring tags. There was no significant difference in non-selective gear in the return of the three tag types. A tag which was non-selective in fishing gear was desired for Chesapeake Bay striped bass research. Tests proved that both streamer and jaw ring tags would fulfill requirements even though some plastic disks were reported to become separated from the stainless steel ring in the jaw tags. It was necessary that a choice be made between the two types. Streamer tags were chosen for use in subsequent portions of the program because import duty on jaw rings made them expensive and more difficult to acquire.

LITERATURE CITED

Calhoun, A. J. 1953. Aquarium tests of tags on striped bass. *Calif. Fish. & Game 39(2):209–18.*

Davis, W. S. 1959. Field tests of Petersen, streamer, and spaghetti tags on striped bass, *Roccus saxatilis* (Walbaum). *Trans. Am. Fish. Soc. 88(4):319–29.*

Vladykov, V. D. 1957. Fish tags and tagging in Quebec waters. *Trans. Am. Fish. Soc. 86(1956): 345–9.*

Atlantic Coast Striped Bass Program, U. S. Bureau of Commercial Fisheries, Beaufort, North Carolina.

Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Thirteenth Annual Session, November, 1960
Pages 113-127

60

Recent Advances in the Control of Shellfish Predators and Competitors

VICTOR L. LOOSANOFF
U. S. Bureau of Commercial Fisheries
Milford, Connecticut

THE PURPOSE OF THIS ARTICLE is to describe briefly several methods of control of shellfish enemies that either came into practical use during recent years or are on the threshold of being employed on a large scale by shellfish industries.

As is well known, the methods of controlling shellfish predators and competitors may be of three basic types, namely, biological, mechanical or chemical. Biological methods, being more natural than those of the other two categories, are preferable in many respects. However, in aquatic environments they are difficult to develop and, perhaps, even more difficult to execute. An example of this was when a ciliate, *Orchitophyra stellarum*, was discovered in gonads of male starfish, *Asterias forbesi,* which were made sterile by the activities of this parasite (Piatt, 1935). Unfortunately, regardless of persistent efforts, we failed to spread the infection among starfish kept in the laboratory aquaria and tanks or in Long Island Sound.

Mechanical methods have been mainstays of shellfish cultivators for many years. Most of us are familiar with starfish mops and dredges, drill traps and, more recently, suction dredges that are in use in this country. The principles of these methods have already been described (Galtsoff *et al.*, 1937; Galtsoff and Loosanoff, 1939). In Europe, for over a century, several types of fences have been in use against crabs and rays. All these methods are partially helpful but none is adequate in itself. As a result, to cite one example, the recent prevalence of drills in Long Island Sound compelled the oyster industry to give up virtually the entire area of Milford Bay, where only a few years ago highly productive beds existed. Almost total extermination by starfish of the extremely heavy 1958 oyster set in Long Island Sound is another example of the inability of oystermen to protect their crops with the methods presently available.

Since it has always been realized that mechanical methods of control are expensive and usually only partially effective, the possibility of using chemical substances to combat starfish and predatory snails, such as oyster drills, was considered on many occasions. During the early 1930's biologists experimented widely with copper sulfate to eradicate starfish (Galtsoff and Loosanoff, 1939). A few years later an effective chemical method, consisting of spreading quicklime over starfish-infested bottoms, was perfected at Milford Laboratory and has been used ever since by several oyster companies in Long Island Sound (Loosanoff and Engle, 1938). This method, unfortunately, has its limitations also, principally because quicklime becomes slaked upon contact with sea water and, therefore, soon loses a great deal of its efficacy.

As often occurs in nature, an oyster or a clam faces its enemies from the very beginning of its existence. Predation begins as soon as the eggs are shed and continues through larval, juvenile and even adult stages. In addition to direct enemies, such as plankton eaters are to early stages of developing bivalves, and as, later on, bottom predators, such as gastropods, starfish, crabs and the flatworms, *Stylochus,* are to recently set bivalves, competing organisms are often of paramount importance. We are all familiar with tunicates, *Crepidula,* barnacles, hydroids, and algae, not to mention mussels, which often set so heavily that they smother recently set oysters by competing with them for space, food and oxygen. Some of these forms, including barnacles and tunicates, act as direct enemies of oysters by eating their larvae and, also, as competitors of more advanced stages when living in the same environment. Because direct and indirect enemies of shellfish are important in mariculture, control measures should be developed for both groups.

As far as I am aware, there is virtually nothing new to report as to recent achievements in the field of biological control of shellfish enemies. Several laboratories are experimenting along such lines, but these experiments have not progressed far enough to give us any assurance that successful methods will be developed. At our laboratory, on the suggestion of our British colleagues, we experimented with the Sun-star, *Solaster papposus,* brought from the waters of New Brunswick, Canada, as a form that would attack and feed upon our common starfish, *A. forbesi.* The results were discouraging because usually the latter acted as the predator.

Contrary to the lack of progress in biological methods, a new mechanical method, which seems to show considerable promise, is now under trial at Milford Laboratory. It consists of burying drills under a thin layer of bottom material (Loosanoff and Nomejko, 1958). Laboratory experiments demonstrated that when buried at a depth of 3 centimeters, approximately 40 per cent of drills, *Urosalpinx cinerea,* could not reach the surface and died. If covered with a layer 6 cm deep, about 92 per cent of drills perished. Later, we discovered that the method is also quite effective against starfish. When buried under 1 inch of mud these pests died within 24 hours and in sand, within 48 hours. Only about 10 per cent of starfish buried with one or two rays protruding from sand could emerge, while the others died and decomposed within three days. F. Mansfield & Sons Company of New Haven is presently under contract with our Bureau to develop mechanical details of an underwater plow to be used for extermination of drills and starfish on bottoms composed of comparatively soft material (Figure 1).

The underwater plow method also appears to be promising in controlling the common mussel, *Mytilus edulis,* which at times occurs in a thick layer covering oyster beds of Long Island Sound. We have reason to believe that the same method will be effective against *Crepidula,* another important oyster competitor.

Probably the greatest progress in recent methods of controlling shellfish enemies has been made in the use of chemicals, especially insecticides. Many of these methods, several of which were developed at Milford Laboratory, are comparatively new and some of them are still undergoing a series of trials. In general, the use of chemical control measures can be discussed in two ways. The first consists of mentioning each enemy separately and then describing the method that is effective against it. The second approach offers, first, a general description of the method and then the names of all enemies that can be controlled by it. For this discussion the second approach has been selected as being more convenient and less time-consuming.

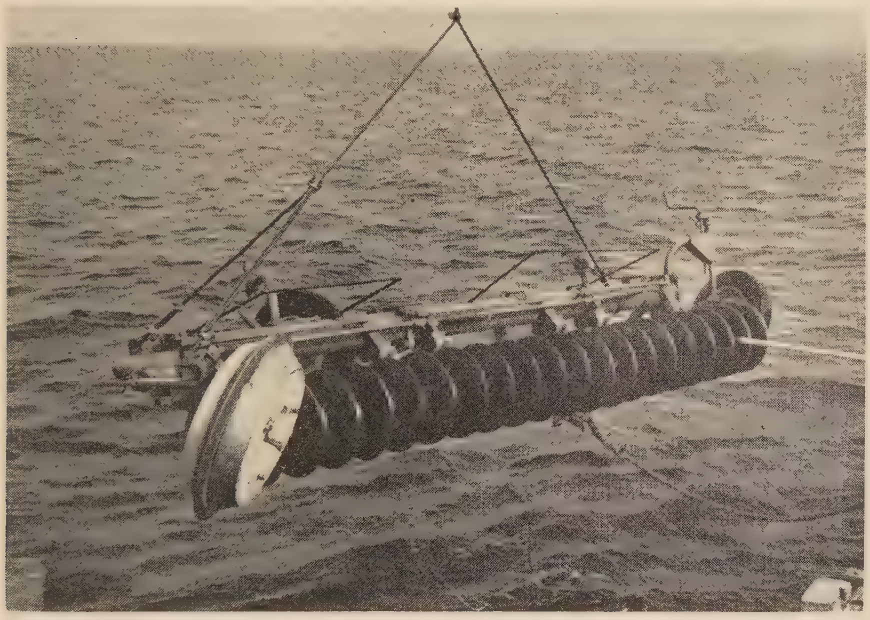


FIGURE 1. Underwater plow, used in control of oyster enemies and competitors, ready to be lowered.

In controlling undesirable aquatic forms chemicals can be used in several ways. They may be (1) dissolved in water; (2) spread over large areas of the bottom as a thin layer which will repel enemies, such as drills, starfish, crabs, etc., or kill them or their larvae upon contact; (3) used in so-called barriers, or belts, made of chemicals mixed with materials of an inert nature, such as sand or fragments of old oyster shells, and laid as a continuous band to surround the oyster bed so that enemies, such as starfish and drills, will be stopped before penetrating into the protected area; (4) combined with shell material of living oysters, old oyster shells, or other spat collectors to make them either unsuitable for the existence of such forms as sponges, worms, and other shell dwelling organisms, or to prevent their fouling with tunicates, hydroids, barnacles, *Crepidula,* worms, algae, and others; (5) combined with shells of dead oysters, or other materials used as cultch, to repel drills or to kill larvae of other undesirable forms, such as flatworms, *Stylochus,* which may set on these shells and attack oyster set. A modification of the latter method may consist of using chemicals which will not only repel enemies but, simultaneously, attract oyster larvae to set in larger numbers on the specially-treated collectors; and (6) incorporated as poisons in foods that will be eaten by shellfish predators, such as horseshoe crabs, crabs, prawns, rays, drumfish, and others.

In addition to the above-mentioned uses, another method of employing chemicals may be suggested. It would consist, in general, of placing on an oyster bed, certain selected compounds, incorporated in organic solvents, that would gradually ooze into the water and create near the bottom, for desirable periods, light concentrations of chemicals that would be, nevertheless, strong enough to eliminate fungus, bacteria, hydroids, algae, and, perhaps, crustaceans and worms, without seriously endangering commercial mollusks or affecting their food value.

Water Solutions

Water solutions of chemicals should be used only under controllable conditions. Therefore, their use may be practical, as a rule, only in small volumes of water, such as laboratory and hatchery troughs and tanks, or in small lakes, ponds, claires, and dikes. Solutions can also be used advantageously for dipping into them, during transplanting operations, dredge-loads of oysters infested with boring sponges, worms, barnacles, etc. In still another case, placing infected bivalves in certain chemical solutions may free them of some internal parasites. We shall consider each of these uses separately.

Solutions of chemicals can be advantageously employed in controlling various forms of zooplankton, especially crustaceans of the sub-class Copepoda, which sometimes interfere with culturing of larval mollusks or invade mass cultures of phytoplankton, such as *Chlorella*, where they multiply rapidly and soon render the cultures worthless. In the past such invasions presented us with rather serious problems since it was virtually impossible to destroy the copepods, chiefly because of the viability of their eggs. Recently, however, we have been using a number of chemicals to prevent the invasions or terminate them (Loosanoff, Hanks and Ganaros, 1957). Several insecticides, which are known under the trade names of Guthion, Dipterex, Parathion, Lindane, TEPP and, more recently, Sevin, a carbamate, have been used for these purposes. The method is simple but effective. For example, in a 1.0 part per million solution of Guthion all crustaceans are killed within 2 hours at room temperature. Complete mortality is also caused by 0.05 ppm of Guthion or Lindane at the end of 20 and 53 hours respectively. The concentrations used, fortunately, do not noticeably affect the normal existence of algal cultures nor do they affect bivalves or their larvae which are fed treated *Chlorella*.

One of the most common offenders in hatchery trays and troughs is a bottom amphipod, *Corophium cylindricum*, which seriously interferes with recently set young clams, *Venus mercenaria*. This crustacean can also be easily exterminated by subjecting it for several hours to a solution of any one of several of the above-mentioned insecticides at a concentration of 1.0 ppm or even lower.

Sometimes, for example, during our experiments on propagation of oysters conducted in an artificial pond on Long Island, large numbers of free-swimming crustaceans become a problem because they compete with oyster larvae. We determined that a concentration of approximately 1.0 ppm of TEPP (tetraethyl phyrophosphate) killed crustaceans without causing serious injuries to oyster larvae. Many bottom crustaceans present in the same pond, which was approximately 1 square acre in area, also were killed, while none of the bivalves appeared to be affected.

Victoria Blue B, a biological stain, is another chemical compound, a solution of which will kill many undesirable forms, including common mussels, annelids, tunicates, certain gastropods, and hydroids. This chemical has been used routinely in our laboratory for over 5 years to check unwanted animal populations in hatchery troughs. The usual practice is to discontinue the flow of sea water through troughs and to create concentrations ranging from 1.0 to 2.5 ppm of the stain. As mentioned above, tunicates, annelids, mussels, and certain other competing bivalves, chiefly those that cannot keep their shells tightly closed, will be killed if subjected to this concentration for several hours. Hard shell clams, however, keep their shells closed and, consequently, remain unaffected. Some oysters, on the other hand, may open their shells during long immersion and receive a lethal dosage of the chemical. The Victoria Blue method, therefore, should be used with considerable care.

Still another modification of using chemical solutions is the so-called dip method. It consists of immersing a dredgeful of oysters, together with other bottom material, into a vat of the solution to destroy all predators and competitors that may be present (Figure 2). This measure prevents transplanting of undesirable forms from one bed to another by killing *Polydora*, boring sponges and other organisms that live within the shells of live oysters. Korringa (1951), using a solution of di-nitro-ortho-cresol at a concentration of 500 ppm, killed the majority of *Polydora* in shells of European oysters in this way within 3 hours. MacKenzie and Shearer (in press) repeated these experiments

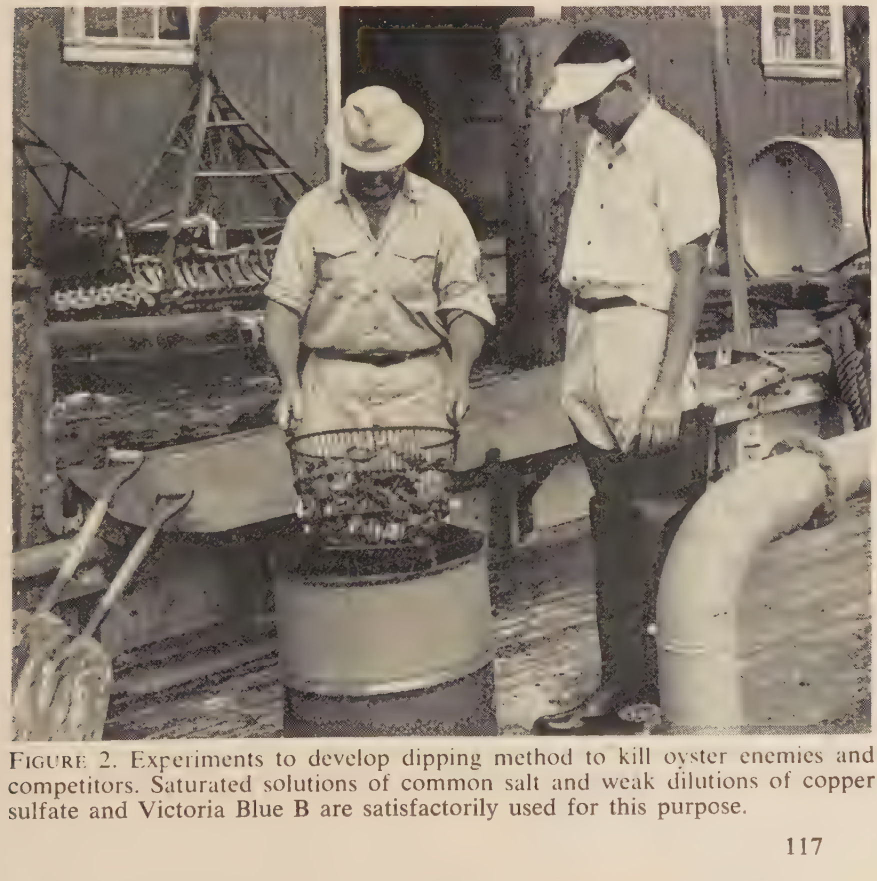


FIGURE 2. Experiments to develop dipping method to kill oyster enemies and competitors. Saturated solutions of common salt and weak dilutions of copper sulfate and Victoria Blue B are satisfactorily used for this purpose.

killing up to 90 per cent of the worms by exposing them from 1 to 3 hours to the above concentrations. However, when these workers used Victoria Blue B at a concentration of 200 ppm, they killed 97 per cent of the worms within only 15 minutes. MacKenzie and Shearer mentioned many other compounds that they found effective in the control of *Polydora* and other annelids inhabiting oyster shells.

The dipping of dredged oysters for different periods in Victoria Blue B and then leaving this material to dry in air also killed many undesirable forms, including tunicates and mussels. A detailed discussion of the use of Victoria Blue, as a practical method for killing oyster competitors, is offered in MacKenzie's article, which is now in press.

Copper sulfate is another compound that may be used advantageously to control oyster enemies and competitors by dipping them in a solution of this chemical. In the past we used this compound at Milford to kill drill embryos (Engle, 1941). Walne (1956) used different concentrations of copper sulfate to destroy fouling organisms on artificial oyster spat collectors. Glude (1957) showed that copper ions will effectively repel adult drills. Still more recently, MacKenzie (in press), in cooperation with local oyster companies, conducted an extensive series of experiments in which copper sulfate was used to kill various oyster competitors. To kill mussels, MacKenzie recommends dipping them into copper sulfate solutions varying in strength from 0.5 to 1.0 per cent, if material is to be kept out of water for 24 hours or longer after dipping, and 1.0 to 2.0 per cent solutions, if it will be stored in air for only a few hours. This treatment kills mussels but does not affect medium and large oysters. However, young oysters, measuring less than 20 mm in length, should not be subjected to it even if the solution contains only 0.5 per cent of copper sulfate.

Another extremely simple but effective and versatile method to kill undesirable forms is the use of saturated or nearly saturated solutions of common salt (Loosanoff, 1958). By dipping the dredged material in a strong salt solution and then allowing it to dry on deck for some time, a wide variety of undesirable organisms can be destroyed. The method is extremely effective in killing shell-boring sponges of the genus *Cliona*. Complete mortality is achieved by immersing them in a saturated solution of common salt for only 30 seconds and then leaving them in air for at least 1 hour. Starfish, two species of *Crepidula*, several species of tunicates, the flatworm, *Stylochus ellipticus*, and many other undesirable organisms, including protozoa, hydroids, bryozoa, algae, and even small crustaceans, are killed by this method.

These experiments also indicated that a saturated salt solution may be helpful in controlling a drill population by killing their eggs and embryos while they are still in egg cases (Loosanoff, 1958). Heavy mortality of drill embryos was observed even when egg cases were immersed for only 3 minutes and then kept in air for several hours before being returned to sea water. Further studies on applications of strong and saturated salt solutions were recently completed at our laboratory, indicating wide application of this method (Shearer and MacKenzie, in press). We think that the dreaded shell disease of European oysters can be kept in check by wide usage of this method.

There remains one more approach to using chemical solutions in control of oyster enemies. It is thought that certain dangerous internal parasites of oysters and European mussels, such as copepods of the genus *Mytilicola*, may be eliminated by placing infested mollusks into solutions of certain insecticides (Loosanoff, Hanks and Ganaros, 1956). The method can probably be made more effective by adding to the solutions a thick algal culture which, after absorbing some insecticide, will be ingested by mollusks and later passed through the digestive tract, certain sections of which harbor parasitic copepods.

Chemical Treatment of Shellfish Bottoms

During recent years it was found that many enemies of bivalves can be controlled by the use of chlorinated oils, such as orthodichlorobenzene (Loosanoff, MacKenzie and Shearer, 1960a; Loosanoff, MacKenzie and Shearer, 1960b). Further experiments indicated that the effectiveness of the treatment can be increased by incorporating in heavy oils other chemicals, such as Sevin, an insecticide which is relatively non-toxic to mammals. The oils are usually mixed with dry sand, broken oyster shells, or other inert materials to "anchor" them on the bottom undergoing treatment.

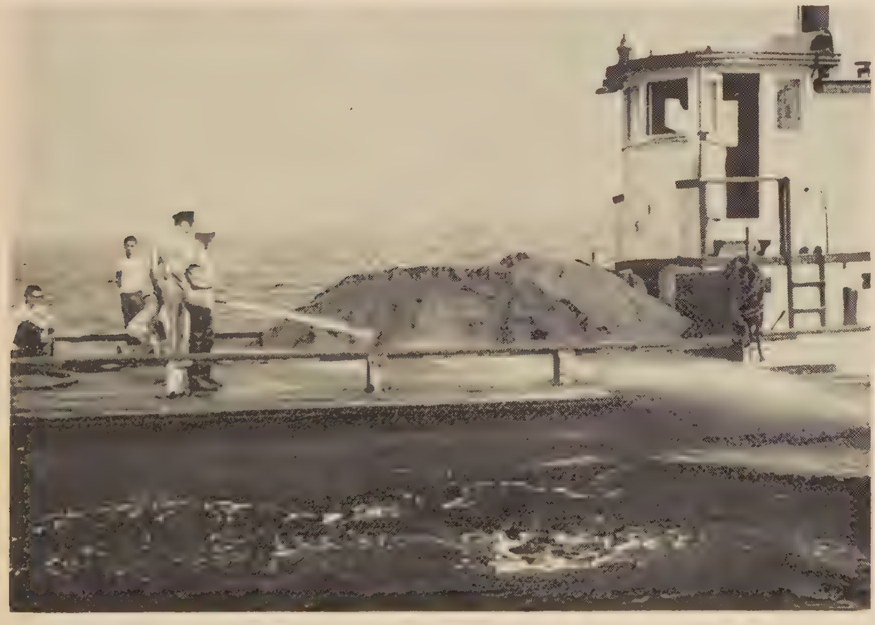


FIGURE 3. Chemically-treated sand being washed overboard with strong stream of water to destroy enemies on oyster beds.

By spreading chemically-treated sand over shellfish beds, several enemies, including oyster drills, can be either almost entirely eliminated or their numbers greatly reduced. The formula that usually gives good results consists of mixing, by volume, 95 per cent of dry sand with 5 per cent of chlorinated benzenes containing from 1 to 3 per cent of Sevin. The sand is spread over the area either by a machine, such as is used when spreading sand on icy highways in winter, or by washing it overboard by means of a powerful stream of water (Figure 3). Several experiments of this nature conducted during the summer of 1960 in Long Island Sound and Great South Bay were quite successful. They will be described in detail later on in other publications.

This method of covering large bottom areas with chemically-treated sand may also be used to kill starfish already on the beds. Particles of sand falling on the upper surface of starfish will imbed in the delicate membrane covering these pests, quickly disintegrate it and eventually cause death.

The same method is also effective in stopping the re-invasion of shellfish beds with a new generation of those enemies that have swimming larval stages, such as starfish, crabs, and flatworms. Ready-to-metamorphose larvae will die soon after they settle on, or move over, the chemically-treated bottom.

Still another reason for spreading chemically-treated sand over oyster growing bottoms is to eliminate the mud shrimp, *Upogebia*, the ghost shrimp, *Callianassa*, and related forms which, by their continued digging activities, render large bottom areas unsuitable for oyster culture (Loosanoff, MacKenzie and Shearer, 1960a). Preliminary experiments conducted on shrimp-infested bottoms of the State of Washington by Cedric Lindsay of the Department of Fisheries have indicated that these methods can be successfully used for this purpose (personal communication).

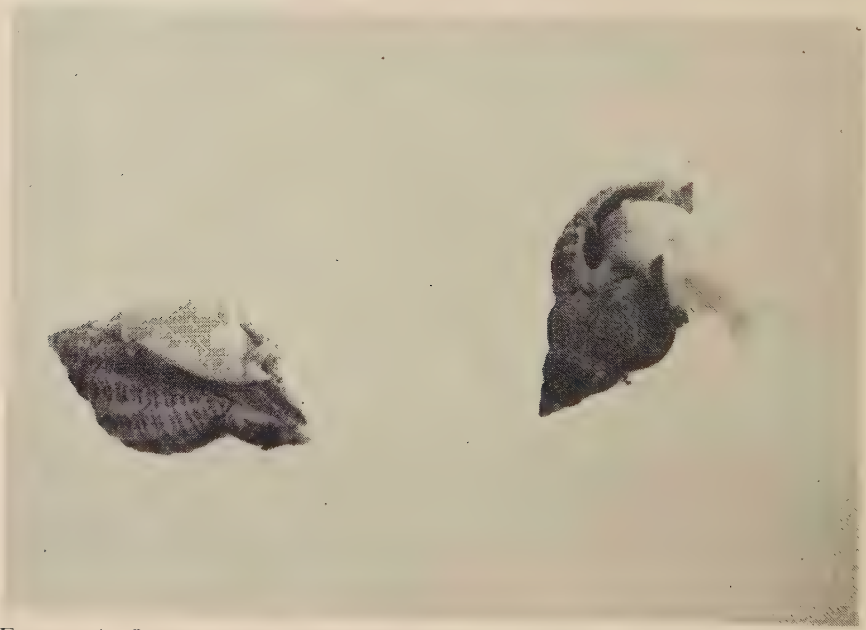


FIGURE 4. Oyster drills, *Urosalpinx cinerea*, swollen after contacting sand mixed with orthodichlorobenzene and Sevin.

Chemical Barriers

Chemical barriers are made of a mixture of sand, such oils as orthodichlorobenzene, and other chemicals, depending upon what enemy or groups of enemies are to be controlled. We found that virtually all gastropods can be stopped by a barrier composed of only sand and heavy oils (Figure 4). However, as already mentioned, the efficiency of barriers can be increased by incorporating in them certain other compounds (Loosanoff, MacKenzie and Shearer, 1960a).

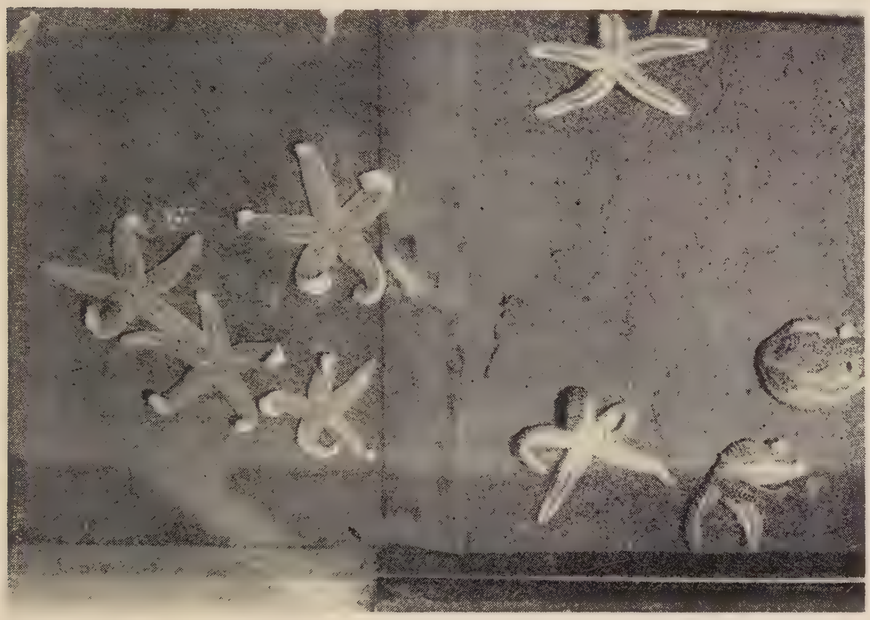


FIGURE 5. Starfish severely affected by chemical after contact with experimental barrier.

Several formulas have already been developed to arrest, under experimental conditions, movements of starfish, *Asterias forbesi* (Figure 5). Other formulas have been developed which seem to be effective in stopping, simultaneously, the movements of boring gastropods, starfish, and crabs. A promising combination for this purpose is orthodichlorobenzene containing small quantities of 2-chloro-1-nitro-propane and Sevin. However, since we do not know much about the toxicology of 2-chloro-1-nitro-propane and this material is expensive and difficult to obtain, another chemical, Rosin Amine D, manufactured by Hercules Company appears to be a good substitute. It will be tried next year on a large scale in Long Island Sound.

Because of recently acquired knowledge and quite extensive field experience, we can now create barriers wide enough and strong enough to stop movements of crabs. It should be remembered, however, that while this method may be safely applied in areas where crabs are of no commercial value, for example, in some waters of New England where the green crab is the chief enemy of the soft clam, in other areas, such as Chesapeake Bay, where the blue crab is an important commercial species, extreme care should be exercised. We hope, nevertheless, that by learning more about the application and special uses of chemical methods, life histories of different organisms populating aquatic basins, and by finding specific poisons that will affect only certain species of a large genus or family, we will eventually succeed in preventing unnecessary losses among useful animals.

We have experimented with barriers laid in laboratory troughs, in the intertidal zone of Milford Harbor, and finally in 20 feet of water on the bottom of Long Island Sound. In all cases we found that the barriers were effective as long as they did not become covered with a heavy layer of silt. During these experiments many interesting and important observations were made. For example, setting of oysters within the areas protected by barriers was just as good as on untreated bottoms. Furthermore, no noticeable mortality occurred among any forms within the barriers and, finally, growth of clams and oysters within the protected zones was just as rapid as in the outside areas established as controls (Loosanoff, MacKenzie and Davis, 1960).

The chemicals composing the barriers retained their strength for a considerable period. For example, the mixture constituting the intertidal Milford Harbor barrier, which was laid on April 19, 1959, was still strong enough to cause swelling of gastropods when tested in October 1960. Our divers also observed that, regardless of several heavy storms and a hurricane, the barrier laid on the bottom of Long Island Sound in 1959 was intact after one year. These observations indicate that, because of their long-lasting effectiveness, the use of barriers may be practical.

Prevention of Fouling

One of several difficulties experienced by oyster growers in this country and abroad is the rapid fouling of cultch. This is especially true when, to collect a new set of oysters, cultch is suspended in water. For example, in Milford Harbor, oyster shells or artificial cultch will be converted into balls composed of numerous fouling organisms within two or three weeks after planting.

Efforts to combat fouling have been carried on at our laboratory for many years. We discovered, quite some time ago, that setting of barnacles on spat collectors can be prevented if they are treated with DDT (Loosanoff, 1947). Our British friends continued these studies using, in addition to DDT, other chemicals, including Lindane (Waugh *et al.*, 1956). Recently, our studies have been considerably expanded. Experiments conducted last summer, which consisted of dipping oyster shells in certain heavy oils and, later, planting them in Long Island Sound for periods of 2 to 3 months, gave encouraging results. Oyster spat were more numerous on shells treated with certain oils, particularly Polystream and Polychlor mother liquor, both of which contain large amounts of tetrachlorobenzene, than on control shells.

These experiments, which were duplicated in Milford Harbor, not only showed that oyster set was heavier on shells treated with Polystream, but also that these shells were virtually free of fouling organisms, including barnacles, tunicates, worms, hydroids, and the protozoan, *Folliculina* (Figure 6). What may be of special significance to the oyster industry of many areas is that shells treated with Polystream also repelled or killed the oyster leech, *Stylochus,* and its set. Extensive experiments to verify these conclusions are planned for next summer in the waters of several states.

Repelling Drills from Set Collectors

In some instances it may be practical to collect oyster set in areas where

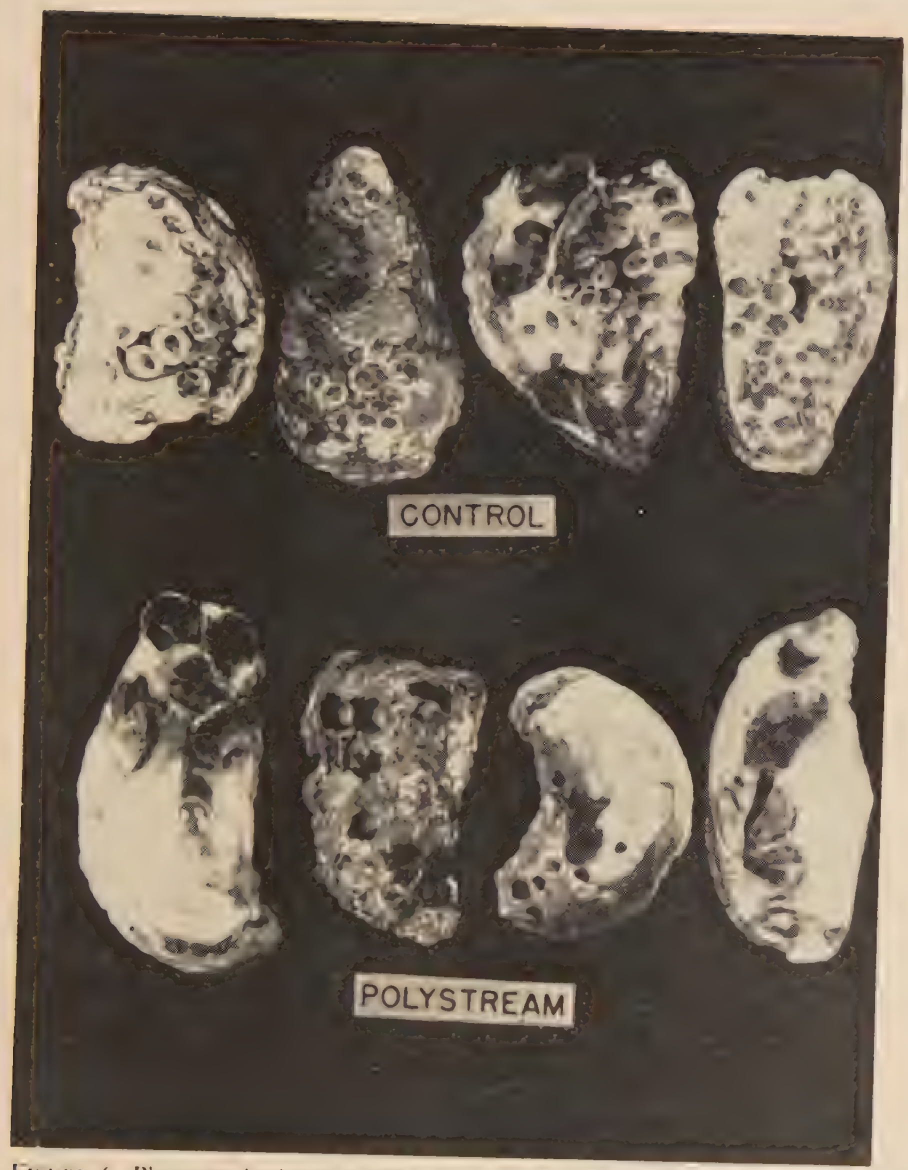


FIGURE 6. Photograph showing differences in intensity of setting of barnacles on Polystream-treated and control shells used as oyster set collectors.

drills are abundant, provided that drills can be kept from attacking young oysters. This may be achieved by chemical treatment of cultch before it is placed in the water. Experiments of this nature were undertaken last year on oyster beds of Long Island Sound and Milford Harbor, and in outdoor troughs with running sea water (Loosanoff, MacKenzie and Davis, 1960). The oyster shells were dipped in one of the following: (1) orthodichlorobenzene; (2) orthodichlorobenzene and kerosene in equal volumes; (3) orthodichlorobenzene, trichlorobenzene and tetrachlorobenzene in equal volumes; and (4) a mixture of equal parts of orthodichlorobenzene, trichlorobenzene and tetrachlorobenzene, to which an equal volume of kerosene was later added. The final mixture was composed, therefore, of 50 per cent of the 3 chlorinated oils and 50 per cent of kerosene.

The results of the experiments were gratifying because they showed that oyster larvae set on oil-treated shells and, what may be even more important, that some of the mixtures, for example, that of 3 chlorinated oils diluted with an equal volume of kerosene, were effective for some time in keeping drills from attacking recently set oysters.

In the summer of 1960 the experiments were expanded by using a much larger number of collectors, new kinds of oils, and conducting observations in more locations. Since, at the time this report is being written, many collectors are still overboard and because the examination of samples is still in progress, we cannot offer final conclusions about the effectiveness of the method. However, we have sufficient evidence to conclude that all groups of shells dipped in chlorinated oils collected oyster set. Furthermore, in several cases oyster spat on oil-treated shells showed better growth than on control shells although, on the basis of present evidence, the rate of growth on oil-treated shells is, in general, somewhat slower. Finally, observations made during the past summer again indicated that drills are reluctant to attack oyster spat attached to shells treated with chlorinated oils. On the basis of the experiments carried on thus far, Polystream and Trimix seem to be the most effective agents to counteract drill activities.

A series of critical experiments to verify these conclusions is already underway. It appears, nevertheless, that the method will prove to be effective because, as soon as drills crawl upon Polystream or Trimix-treated shells, many of them swell and become unable to move. Probably touching the crystals of these oils, which can be seen on shells removed from the water even after being overboard for several months, affects the drills soon after their bodies come in contact with them. The method does not offer complete protection because some drilled oyster spat were found even on the treated shells. We hope, however, that by adding certain other chemicals to Polystream this will be prevented.

Baits

Use of chemically-treated baits to poison undesirable aquatic species, such as crabs, horseshoe crabs, rays and drumfishes, occurred to biologists some time ago. Our observations that crabs feeding on barnacles dipped in a solution of DDT went into convulsions soon after feeding, and similar observations by Dr. F. Gross of England (personal communication) led us to believe that poisoning of crustaceans can be simply accomplished by using insecticides. In our screening of several thousand chemicals, which were tested on approximately 10 different species of oyster enemies, we found many that can be used either in bait or in solution to kill most crustaceans that have been exposed to these poisons. To determine the effectiveness of these substances on the group of marine arthropods that has presented or can present problems in shellfish conservation or in other aspects of mariculture, we used the following species:

Rock crab	*Cancer irroratus*
Blue crab	*Callinectes sapidus*
Lady crab	*Ovalipes ocellatus*
Mud crab	*Panopeus herbstii*
Green crab	*Carcinides maenas*
Hermit crab	*Pagurus pollicaris*
Spider crab	*Libinia emarginata*
Common sand shrimp	*Crangon vulgaris*
Mantis shrimp	*Squilla empusa*
Horseshoe crab	*Limulus polyphemus*
Copepods	(several species)

The results showed that all these forms can be quickly affected (Loosanoff, Hanks and Ganaros, 1956). A list of over 100 substances, which were found effective in our experiments against crabs, has recently been published (Loosanoff, 1960). We recommend Sevin, one of the insecticides that is least toxic to humans and fish, for incorporation in bait to kill crabs. Our colleagues at Boothbay Harbor, Maine, have made prolonged studies on the use of Lindane in control of green crabs and have recently reported results of their extensive and convincing experiments showing that control of these crabs can be easily accomplished by proper use of chemicals (Hanks, in press).

The use of poison bait distributed on the bottom, perhaps in the form of pellets composed of agar, clam meat and a poison and made heavy enough to sink by addition of sand, may also help us to solve a number of problems where crabs are intermediate hosts in transmission of diseases. For example, we are all familiar with the fact that the sporozoan, *Nematopsis,* quite commonly found in oysters, is transmitted by mud crabs. In the past, heavy mortalities of oyster populations have been ascribed to these gregarines. At present, another extremely serious mortality of epizootic nature is raging in the waters of several states along our Atlantic coast. The organism, which is suspected of being responsible for this mortality and which, at present, is called MSX, is also a sporozoan and, presumably, may pass the intermediate stage in the body of certain crustaceans, perhaps mud crabs or bottom shrimps. Because we now have several methods to exterminate crustaceans we may, in the near future, prevent spreading of several diseases by destroying intermediate hosts of parasites.

Other Uses of Chemicals

In many areas the oyster crab, *Pinnotheres ostreum,* is very common. This crab, living inside of oysters, usually causes considerable damage to their bodies and, in general, affects their quality, in some instances even causing death. These parasites, and they are true parasites, may be controlled or entirely eliminated by using various modifications of the chemical methods mentioned in this paper. A little experimentation along these lines will probably point towards a simple but effective approach. We suggest that it consist of placing on an oyster bed, where such crabs are prevalent, certain organic solvents in which other chemicals, probably such insecticides as Sevin, are incorporated. These chemicals will dissolve at a comparatively slow rate and create an extremely light concentration of the insecticide near the bottom. This concentration, nevertheless, will be strong enough to kill the crabs in a few days. Perhaps our method of covering bottom areas with chemically-treated sand, which we recommend for control of drills, will be applicable. Next summer we intend to ascertain its effectiveness against *P. ostreum*.

I could continue with further suggestions about what can be done to control shellfish enemies not mentioned in this article, but it would be impractical because of the large number of cases to be considered. This article cannot be terminated, however, without mentioning that chemical methods may also be useful in control of shellfish diseases due to bacteria or fungi, such as the widespread fungus disease of southern oysters caused by *Dermocystidium*. This may again be accomplished by incorporating certain fungicides in the heavy oils and, after mixing the oils with dry sand, spreading the mixture over an oyster bed or surrounding the bed with a belt of this material. The slowly dissolving fungicides will gradually leave the oils and spread in a thin layer over the oyster bed, possibly creating concentrations, which will be sufficient to kill fungus already infesting the oysters or to prevent infestation of healthy oysters by fungus. Similar methods can probably be applied to control other microorganisms responsible for heavy oyster mortalities, including bacteria and, perhaps, even viruses.

In conclusion I want to emphasize that we fully realize that any chemical entering the water becomes a pollutant. Fortunately, the organic solvents that we employ in our formulas are virtually insoluble in water and, therefore, are relatively safe to use in an aquatic environment. Nevertheless, we are concerned with the potential danger of indiscriminate usage of large quantities of chemicals in aquatic controls. We also think that any compound to be used on shellfish beds on a large scale should be thoroughly evaluated by experienced biologists in terms of its danger to aquatic forms and, of course, in relation to human safety.

In other words, before the use of any chemical is generally recommended, a critical evaluation of the desirability of its usage should be made by comparing its positive and negative values. In our case, it will be especially important to determine the effects of chemicals on commercial species of shellfish, especially whether these compounds accumulate in the bodies of these mollusks rendering them undesirable or dangerous as food. Therefore, regardless of what components are recommended for the final formulas, their safety to humans will be fully established in accordance with recommended procedures.

LITERATURE CITED

ENGLE, JAMES B.

1941. Further observations on the oyster drills of Long Island Sound with reference to the chemical control of embryos. Trans. Natl. Shellfish. Assoc., pp. 1-3.

GALTSOFF, PAUL S., HERBERT F. PRYTHERCH AND JAMES B. ENGLE

1937. Natural history and methods of controlling the common oyster drills (*Urosalpinx cinerea* Say and *Eupleura caudata* Say). U. S. Dept. of Commerce, Bureau of Fisheries, Fishery Circular 25: 1-24.

GALTSOFF, PAUL S. AND V. L. LOOSANOFF

1939. Natural history and method of controlling the starfish (*Asterias forbesi*, Desor). Bull. U.S. Bur. Fish., *49* (31): 75-132.

GLUDE, JOHN B.

1957. Copper, a possible barrier to oyster drills. Proc. Natl. Shellfish. Assoc. (1956), *47*: 73-82.

HANKS, R. W.
In press. Developments in chemical control of the green crab. Proc. Natl. Shellfish. Assoc. (1960).

KORRINGA, P.
1951. The shell of *Ostrea edulis* as a habitat. Arch. Neerl. Zool., *10:* 32-135.

LOOSANOFF, V. L.
1947. Effects of DDT upon setting, growth and survival of oysters. Fishing Gazette, *64* (4): 94, 96.
1958. New method for control of enemies with common salt. Comm. Fish. Rev., *20* (1): 45-47.
1960. Some effects of pesticides on marine arthropods and mollusks. Trans. of the 1959 Seminar, U.S. Dept. of Health, Education and Welfare, Pub. Health Service Tech. Report W60-3, pp. 89-93.

LOOSANOFF, V. L. AND J. B. ENGLE
1938. Chemical control of starfish. Science, *88* (2274): 107-108.

LOOSANOFF, V. L., J. E. HANKS AND A. E. GANAROS
1956. Chemical control of shellfish enemies promising. Natl. Fisherman, *37* (11): 16, 40.
1957. Control of certain forms of zooplankton in mass algal cultures. Science, *125* (3257): 1092-1093.

LOOSANOFF, V. L., C. L. MACKENZIE, JR. AND H. C. DAVIS
1960. Progress report on chemical methods of control of molluscan enemies. Bull. U.S. Bur. Comm. Fisheries, Biol. Lab., Milford, Conn., *24* (8): 1-20.

LOOSANOFF, V. L., C. L. MACKENZIE, JR. AND L. W. SHEARER
1960a. Use of chemical barriers to protect shellfish beds from predators. Fisheries, Fish Farming, Fisheries Management, Wash. State Dept. of Fish., Seattle, Wash., Chapt. 9, pp. 86-90.
1960b. Use of chemicals to control shellfish predators. Science, *131* (3412): 1522-1523.

LOOSANOFF, V. L. AND C. A. NOMEJKO
1958. Burial as a method for control of the common oyster drill, *Urosalpinx cinerea,* of Long Island Sound. Proc. Natl. Shellfish. Assoc. (1957), *48*: 83-89.

MACKENZIE, C. L., JR. AND L. W. SHEARER
In press. Chemical control of *Polydora websteri* and other annelids inhabiting oyster shells. Proc. Natl. Shellfish. Assoc. (1960).

MACKENZIE, C. L., JR.
In press. A practical chemical method for killing oyster competitors. Comm. Fish. Rev.

PIATT, J.
1935. Discovery of important parasites of starfish. Fish. Serv. Bull., *247:* 3-4.

SHEARER, L. W. AND C. L. MACKENZIE, JR.
In press. The effects of salt solutions of different strengths on oyster enemies and competitors. Proc. Natl. Shellfish. Assoc. (1960).

WALNE, P. R.
1956. Destruction of competitive organisms on artificial oyster-spat collectors. Extr. du Journ. du Conseil Internatl. pour l'Explor. de la Mer, *22* (1): 75-76.

WAUGH, G. DUNCAN AND A. ANSELL
1956. The effect, on oyster spatfall, of controlling barnacle settlement with DDT. Ann. Appl. Biol., *44:* 619-625.

Reprinted from Science, June 30, 1961, Vol. 133, No. 3470, pages 2070-2071

Copyright © 1961 by the American Association for the Advancement of Science

Partial Metamorphosis in Anomia simplex

Abstract. Many larvae of the common bivalve, *Anomia simplex*, when grown under laboratory conditions, exhibited a partial metamorphosis. They attained a considerably larger size than that at which larvae normally set. The partial metamorphosis was also characterized by the disappearance of velum, but the retention of a functional foot. Moreover, these organisms were not able to attach to the substratum, and their shells showed a distinct demarcation line between larval and adult portions.

The plain jingle shell, *Anomia simplex*, is a common bivalve of our Atlantic coast. In Long Island Sound its period of reproduction occurs virtually simultaneously with that of the American oyster, *Crassostrea virginica*, and during a large part of the summer the larvae of both these species, which to some extent resemble each other, are found in plankton. *Anomia simplex* is one of approximately 20 species of bivalves, the larvae of which have been grown from eggs to metamorphosis at our laboratory (*1*). An interesting observation was made during our studies of *A. simplex* of what appeared to be partial metamorphosis of its larvae and is described in this report.

Metamorphosis, or setting, of *A. simplex* larvae may begin when they are only about 180 to 195 μ long. More commonly, however, this event occurs when the individuals are approximately 200 μ long, although the largest swimming larvae found in our cultures measured 215 by 210 μ.

Normally, larvae of *A. simplex* approaching metamorphosis drop to the bottom and begin crawling by means of a strong foot, which is developed during the late swimming stages. Upon finding a clear hard area, such as an oyster shell or rock, the metamorphosing organisms attach to it by means of a special byssus that later becomes calcified. From then on a young *Anomia* is unable to move, and it soon completes the process of metamorphosis which, in part, consists of a resorption and disappearance of the foot and velum. Meanwhile, well-developed gills become visible through the semitransparent shell.

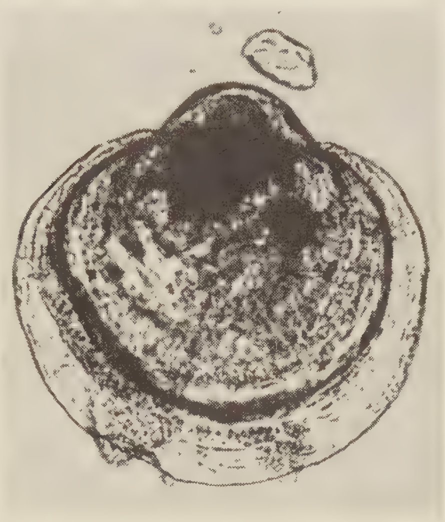


Fig. 1. Photomicrograph of young *Anomia simplex* during the stage of delayed metamorphosis. A definite line dividing prodissoconch and dissoconch portions of the shell and part of the protruding, still functional foot are visible. The size of the organism is about 255 μ.

In our cultures, however, we observed hundreds of individuals, which were considerably longer than 215 μ, but which were, nevertheless, still crawling on the bottom by means of a ciliated foot. The largest individual, which possessed such a well-developed foot but no velum, measured 577 by 514 μ. All these animals had certain features in common, namely that, although the gills were already well formed and the velum was entirely absent, the powerful functional foot was still present and the animals remained unattached. The last two conditions clearly indicated that the young mollusks had not yet entirely metamorphosed.

Closer examination of these individuals showed that they all had another peculiarity in common—the presence of a definite narrow band in their shells which, apparently, indicated the edge of the prodissoconch, or larval shell, and the beginning of the dissoconch or postlarval shell (Fig. 1). The dividing band was probably formed during an important event in the life of the young mollusks, possibly at the time the velum was resorbed or when some other equally important anatomical or physiological change occurred. Measurement of the inner, prodissoconch, shells surrounded by this band usually gave a length of approximately 200 μ, the size at which setting or metamorphosis of the majority of normal larvae occurs. This older portion of the shell, surrounded by the band, was usually somewhat darker than the outer, more recently formed portion.

Fortunately, we also observed several recently attached individuals which, before setting, had passed through the stage of partial and delayed metamorphosis but which, nevertheless, finally succeeded in attaching to the substratum. In all cases a formerly large foot was in the latest stages of resorption, thus indicating that these young mollusks were completing an abnormally prolonged metamorphosis.

Several reasons may be advanced to explain why some individuals could not normally metamorphose at the proper time. One possibility is that either the absence or presence of some substance in the water, in which the larvae were grown, interfered with the normal progress of metamorphosis. The second, and perhaps more probable explanation, is that the normal setting of larvae was delayed because they could not find the proper substratum for attachment. The importance of such environmental factors, often affecting settling and metamorphosis of many invertebrates in aquatic communities, was well reviewed by Wilson (*2*).

In some of Wilson's early experiments it was clear that the condition which caused the delay in metamorphosis of larvae was the lack of sand on the bottom. Wilson suggests that phenomena of this kind may be general, and the choice of the substratum on which the metamorphosing organisms wish to settle depends as much on its microbiological characteristics as upon its chemical and physical characters. Since, in our experiments, all the vessels in which the cultures of *A. simplex* were grown were of glass, perhaps the smoothness of the material and its composition did not offer the necessary chemical or physical stimulus for normal metamorphosis. However, although the explanations are plausible, they do not appear to be well based because they fail to explain why only certain individuals in the cultures behaved in an abnormal way, while others, usually the majority, metamorphosed normally at the expected size. Nevertheless, our observations of partial metamorphosis of *A. simplex* suggest many interesting experiments on this and related species that may help us to understand and explain certain aspects of the importance of various chemical and physical factors in the environment, especially of the substratum, on metamorphosis of lamellibranch larvae.

V. L. Loosanoff

Biological Laboratory,
U.S. Fish and Wildlife Service,
Milford, Connecticut

References

1. V. L. Loosanoff and H. C. Davis, *Biol. Bull.* **98**, 1 (1950); V. L. Loosanoff, *Am. Scientist* **42**, 4 (1954); H. C. Davis, *U.S. Fish Wildlife Serv. Fishery Bull. No. 136* (1958), p. 58.
2. D. P. Wilson, in *Perspectives in Marine Biology*, A. A. Buzzati-Traverso, Ed. (Univ. of California Press, Berkeley, 1958).

8 March 1961

Bureau Studies Yellowtails to Balance Market Here

(The Port of New Bedford, flounder capital of the world, relies on the yellowtail species to make up the bulk of its flounder catch. In this article, a fisheries biologist describes the economic ups and downs of the fishery as it has affected the New Bedford fishing industry, current studies of the yellowtail species and steps which could be taken by city fishermen to prevent future over-production with its subsequent price declines.)

By FRED E. LUX
Fishery Research Biologist, U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Biologist Laboratory, Woods Hole, Mass.

Early last Fall conditions were looking fairly good for yellowtail fishermen, all things considered. Weather was fine, large catches of yellowtail weren't too hard to locate, and the price of about a dime a pound was reasonable. A fisherman could expect tolerable wages for his long, wearying hours spent on the boat. New Bedford draggers sped to the producing grounds: Georges Bank, the "Channel," Nantucket Shoals, and off Nomansland.

Then as weather continued good and trip after trip of yellowtail was landed, the stocks of them on hand in the processing plants built up. The supply of fish reached, and then exceeded, the demand for them and the price fell. By mid-November small yellowtail were going for as little as ½-cent a pound, and the price of large ones also had been pushed down.

Losses Heavy

Fishermen who were unlucky enough to sell their fish on a day when many trips were offered for sale lost heavily. A number of them chose to dump their catches back into the sea rather than sell at the rock bottom prices.

Finally many of the protesting fishermen simply stopped fishing. Surpluses were rapidly used up and an increased demand for yellowtail was restored. The price quickly rose to earlier levels and fishermen resumed fishing. The crisis had passed, but meanwhile many people had been hurt and thousands of pounds of potentially valuable yellowtail had gone to waste.

The story of such an upset in the balance between supply and demand is an old one in fisheries the world over. It has been repeated many times in New England's fisheries. Last year it was yellowtail and sea scallops. Before that other fisheries have been hit, most of them more than once.

Explanation Cited

These upsets generally come about when unusually large supplies of fish, which the industry is unable to absorb, suddenly become available on the fishing grounds. An explanation of what caused last Fall's crisis in the yellowtail fishery may be gained from the results of yellowtail studies.

A biological study of yellowtail is currently in progress at the Bureau of Commercial Fisheries Laboratory in Woods Hole. A principal aim of this study is to learn how the yellowtail may be harvested most fully and efficiently without damaging this valuable resource.

As a part of the study, samples of the yellowtail dragger catches have been obtained regularly since 1957. We measure the fish in each sample in order to keep a record of the sizes of yellowtail that make up the landings. In addition, we takes scales from some of the fish and examine them to learn the ages of yellowtail being caught.

Since the size and age makeup of the landings change from year to year we must sample catches on a continuing basis to keep up to date with the changes.

Sizes Shown

The average sizes of yellowtail at ages of from 1 to 7 years are shown in the accompanying photograph. These fish were caught on the fishing ground south of Nomansland. We have found that the fish there reach market size, about ½ pound, during their third year. Or, in other words, between their second and third birthdays.

They grow fast during this year and more than double their weight. Yellowtail from the other fishing grounds grow slightly faster than those from the Nomansland ground.

In addition to giving us the size and age makeup of the landings, our samples can tell us in what years a high abundance of yellowtail was spawned. They also show us how these strong hatches, when grown to market size, affected the landings of yellowtail.

We call the fish spawned in a given year the year-class of that year. The 1955 year-class, for example, is made up of all yellowtail that were spawned in 1955

Unusually large numbers of yellowtail were spawned in the year-classes of 1955 and 1956 and fish from them have helped greatly to raise yellowtail landings in recent years. By 1960 many yellowtail from these two strong year-classes were still being caught as 4-and 5-year-old fish which, as our growth picture shows, were of large size.

In addition, a strong year-class of yellowtail was spawned in 1958 and fish from it had grown to small marketable size by the Fall of 1960. During last Fall there were, then, three strong year-classes upon which the fishery was operating, two of which consisted of large fish and one of small fish.

Besides this, some fish were present from other more normal-sized year-classes spawned in 1954 and 1957. When this high abundance of yellowtail was combined with good fishing weather the result was greatly increased landings and finally a collapse of the market because of overproduction.

Oversupply Blamed

The landing of large amounts of small fish when there was little demand for them because of the good supply of big fish probably was much to blame for the drastic price drop.

Our information shows that most of these small fish, which were 2-year-olds from the 1958 year-class, came from grounds southeast of Nomansland. Apparently the 2-year-old fish were abundant on this ground and large, older fish were scarce. Catches from the other grounds consisted of bigger fish.

It may not be possible to completely prevent occasional overproduction in our fisheries. In the yellowtail fishery, however, there appears to be an immediate measure that could be taken to lower the chances of an overproduction crisis arising.

Fish below ¾ of a pound are undesirable from a market standpoint because it is uneconomical to fillet them. As many of the fishermen themselves have suggested, the market can probably be stabilized somewhat if these samll fish are not landed. The yellowtail growth rate shows that the small fish, if left in the water, will rapidly grow to good marketable sizes and can be harvested at a later date.

Information Needed

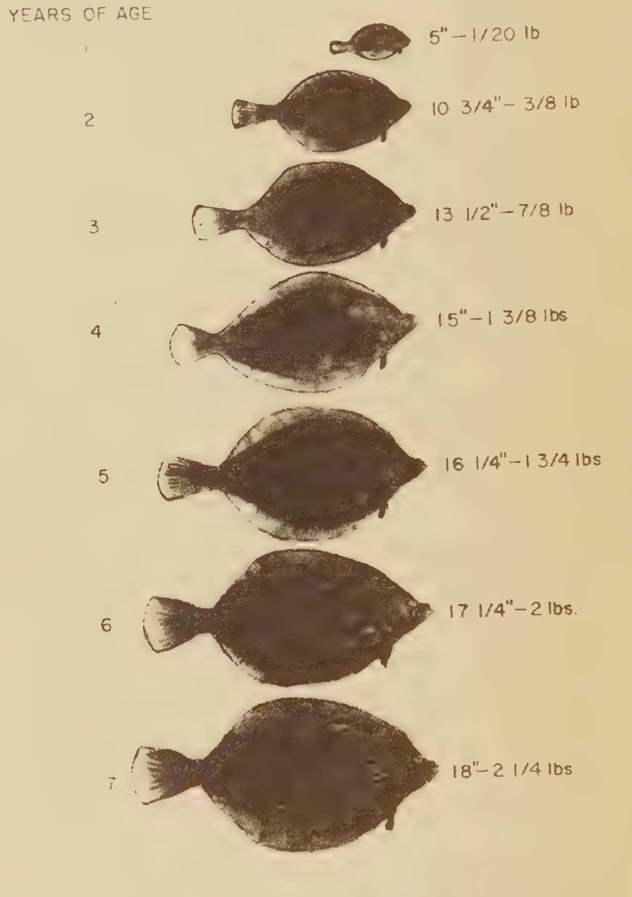
At what size should yellowtail first be taken in landings in order to insure that the fishing fleet obtains the greatest possible poundage of fish from each year-class?

We hope that within about a year our studies of yellowtail growth- and death-rates will give us the information we need to answer this question Market demand alone suggests that fish below about 13 or 14 inches should not be taken

Once we know what the size of yellowtail at first harvest should be we can go ahead with work to learn how the fish below this size can be spared to grow larger.

All yellowtail are caught by otter trawls, and the simplest way of saving undersized fish is to make these nets of large meshes through which the fish can escape. Net selection studies can tell us what mesh size will release most of the small fish but retain marketable ones.

On a voluntary basis, some of the New Bedford fishermen have started using larger mesh nets to allow little yellowtail to escape. Reports from them indicate that this conservation measure has been useful in reducing the numbers of undersized fish caught.



Bureau of Commercial Fisheries Photo

AVERAGE LENGTHS and weights of 1-to-7-year-old yelltowtail flounder caught on the fishing grounds off Nomansland.

Reprinted from: Sunday Standard-Times,

New Bedford, Mass., Feb. 26, 1961

OCEANOGRAPHY AND NORTH PACIFIC ALBACORE

JAMES W. McGARY[1]
Oceanographer

and

JOSEPH J. GRAHAM and TAMIO OTSU
Fishery Research Biologists, Honolulu Biological Laboratory[2]
U.S. Bureau of Commercial Fisheries, Honolulu, Hawaii

The purpose of this presentation is to summarize briefly the Honolulu Biological Laboratory's (HBL) oceanographic studies in the North Pacific and the oceanographic features with which are associated albacore distribution and abundance. These studies were begun in 1954 following two rather significant developments. On the negative side, the Washington and Oregon landing had fallen from a high of 34 million pounds in 1944 to less than a million pounds in 1953. On the positive side, at least scientifically, recoveries of albacore tagged with the ''spaghetti'' tag (Wilson 1953) had clearly demonstrated that the albacore could and did migrate from the American to the Japanese fishery (Ganssle and Clemens 1953), thus giving evidence that the oceanwide stocks are interrelated.

The HBL oceanographic and biological surveys north of Hawaii were planned to determine (1) the geographical limits and relative abundance of albacore and (2) the relationship, if any, of these to the environment, as described by oceanographic data. These studies were coordinated with those of the other research agencies through an informal Albacore Steering Committee composed of representatives of the Bureau of Commercial Fisheries and the States of Washington, Oregon, and California.

Three years were alloted for exploratory cruises to determine the distribution of albacore in the North Central Pacific, and three for the study of their abundance, migrations, and seasonal fluctuations in abundance. The latter effort was based on the premise that concentrations of commercial potential would be found. The results of a commercial charter in 1958 were disappointing, primarily because the locations of commercial concentrations of albacore are subject to large annual variations.

The major portion of both the fishing and oceanographic efforts have been to the west of 140° W. longitude. Cruises have, however, been made to the coastal areas in cooperation with other agencies and as part of our studies of the geographical and seasonal limits of albacore and their migration routes. There has been at least one complete systematic fishing survey, with limited oceanographic observations, of the 'area north of the Hawaiian Islands from 180° to the west coast of North America during each season of the year.

Both the oceanographic features and the summer distribution of albacore indicate that the area can be divided at about 150°-135°W. longitude, and we will follow this division in our discussion.

Figure 1 shows the extent of our oceanographic coverage to the west of 140°W. All the cruises were made in summer or winter with the exception of one made during the 1954 September-November period.

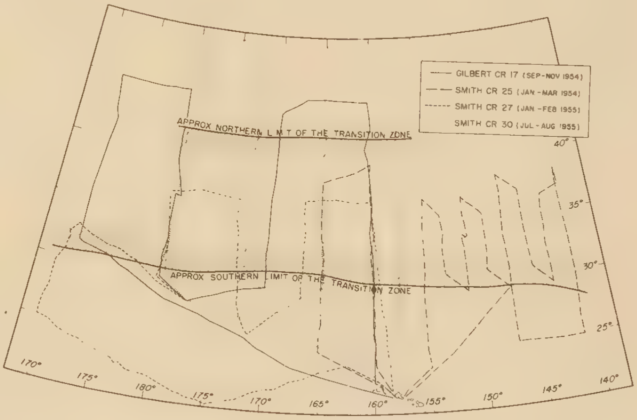

GILBERT CR 17 (SEP-NOV 1954)
SMITH CR 25 (JAN.-MAR 1954)
SMITH CR 27 (JAN.-FEB 1955)
SMITH CR 30 (JUL-AUG 1955)
APPROX NORTHERN LIMIT OF THE TRANSITION ZONE
APPROX SOUTHERN LIMIT OF THE TRANSITION ZONE
40°
35°
30°
25°
170°
175°
180°
175°
170°
165°
160°
155°
150°
145°
140°

FIGURE 1. Tracks of four HBL oceanographic cruises to the central North Pacific.

Figure 1 is from an earlier paper (McGary et al., 1958) in which the oceanographic features were reviewed in a discussion of the possible enrichment patterns of the area. In that report the term ''Transition Zone'' was used to refer to the area in which the water characteristics changed from those typical of the two central North Pacific Water masses to those of the Subarctic Water mass. It was used because the authors preferred to avoid the use of the term ''Polar Front'', which implies a single, abrupt change. Oceanographic data showed, instead, a series of small but frequently abrupt changes. Furthermore, the large seasonal migration attributed to the Polar Front was only apparent in the surface temperature field. The zone of most abrupt change observed in winter at about 35°N. is not comparable in structure or origin to the similar zone located farther north during summer at about 43°-46°N.

Present address: Office of Naval Research, Washington 25, D.C.

Formerly known as the Pacific Oceanic Fishery Investigations (POFI).

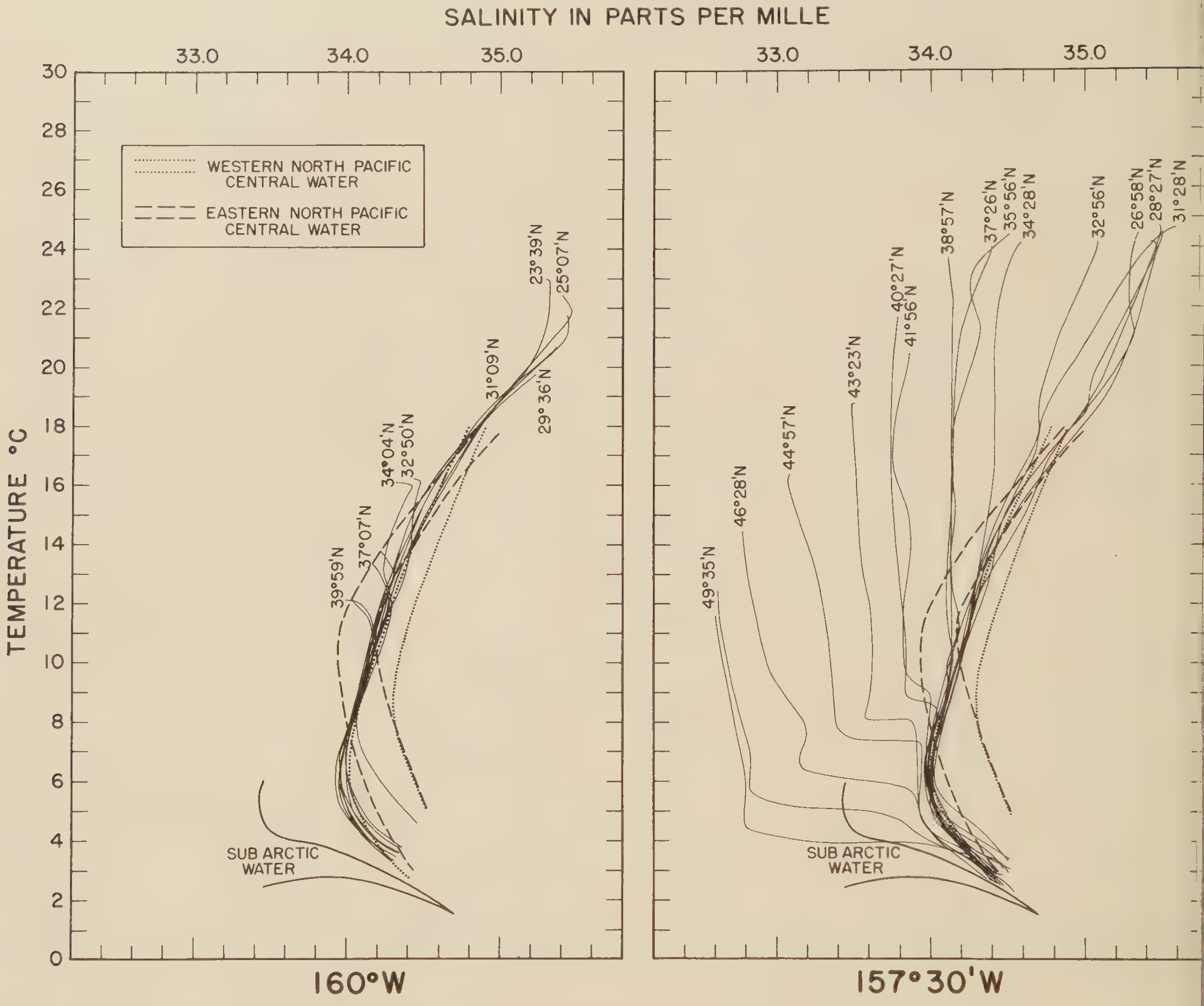


FIGURE 2. LEFT PANEL—superimposed temperature-salinity curves for the meridional station series along 160°W. longitude *Hugh M. Smith* cru 25, January 1954. RIGHT PANEL—same along 157°W. longitude *Hugh M. Smith* cruise 30, August 1955 (McGary et al. 1958).

The temperature-salinity curves (fig. 2) from HBL winter and summer cruises, in the vicinity of 160°W., show the features used in a preliminary definition of boundaries, as well as the effect of seasonal temperature changes in the surface portion of the curves. Those from *Hugh M. Smith* cruise 25, January 1954, (McGary and Stroup 1956), show an abrupt shift in the T-S characteristics of the surface waters between 31°09′N. and 32°50′N. Shifts in the T-S curves continued northward and corresponded to areas of relatively large geostrophic currents. The position of the northern boundary cannot be defined with confidence, since this cruise did not extend far enough north to reach Subarctic Water. T-S curves from *Hugh M. Smith* cruise 30 (NORPAC)[3] (McGary et al., 1958; Hida 1957) shows two regions of abrupt shift in the surface portions of the curves. The m abrupt shift occurred between 32°56′N. and 34°28′ Farther to the north another such shift occurred tween 41°56′N. and 43°23′N. North of that latitu the shifts were large but were uniform latitudinal At 43°23′N. and northward, a salinity minimum w present at the surface, which is in keeping with t definition of Subarctic Water (Sverdrup et al., 19 p. 722).

The salinity cross sections were examined a boundaries roughly set by the following criteria (fig. 3). The southern boundary was set as the nor ern limit of the area within which the warming d ing all seasons was sufficient to maintain a lens high salinity water at the surface. The north boundary was taken as the southern extreme of area in which the lens of low salinity water, fr precipitation or other sources, was sufficient to wi stand the effects of winter cooling or was not mix

---

[3] NORPAC was the code name given to a quasi-synoptic oceanographic survey of the North Pacific during the summer of 1955 by research agencies of Canada, Japan, and the United States.

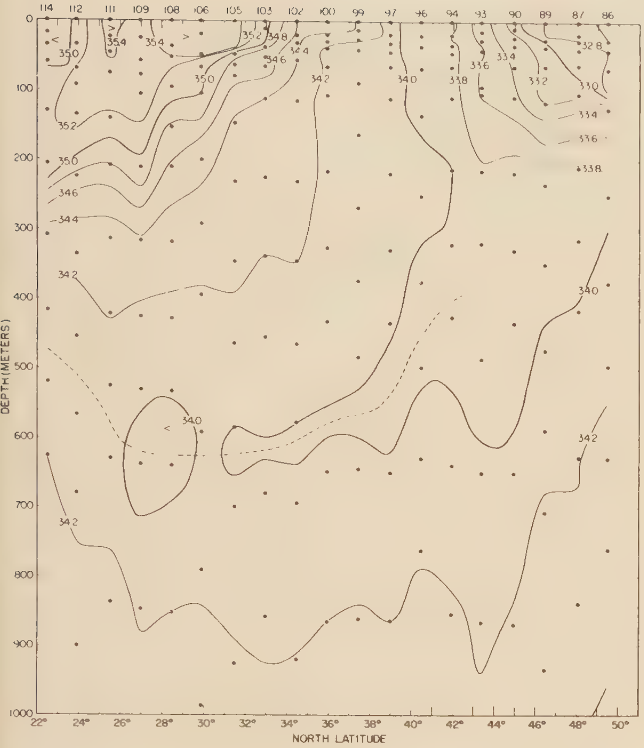


FIGURE 3. Salinity cross section 157°30′W., *Hugh M. Smith* cruise 30, August 1955.

sufficiently with more saline water to the south to cause it to sink even during winter. The limits of the Transition Zone shown in figure 1 were drawn on this basis. The differences in the sections for the various seasons showed, as expected, that the southern limit was 1°-2° of latitude farther south in winter than in summer. Only summer data were available to the north but no doubt the northern limit shifts to the north in winter, since cooling would break up the shallow southern limit of the lens.

Comparison of the longitudinal sections from *Hugh M. Smith* cruise 25 (January-March 1954) showed that boundaries and sharp changes in the T-S curves became less distinct from west to east (Stroup and McGary, 1956).

Reports by Japanese oceanographers suggest that the Transition Zone extends westward to the area immediately off Japan and that it narrows to the west. Uda (1943) described a double frontal system in the Kuroshio, and Masuzawa (1957) discussed the structure in more detail. The latter reported the width of the "Frontal Zone" between the warm and cold water to be 200-300 miles within about 500 miles of the coast. In general, he stated that the "Polar Frontal Zone" shows particularly predominant discontinuities along both the northern and southern edges. He also found that the northern edge was not as well defined as the southern edge.

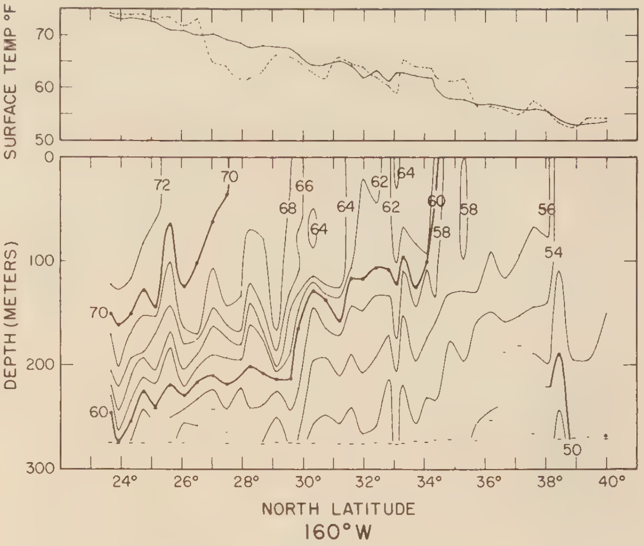


FIGURE 4a. Temperature section from BT casts along 160°W., *Hugh M. Smith* 25, January 1954. Broken line in upper panel shows surface air temperature.

The surface and vertical temperature distributions typical of the Transition Zone are shown in figure 4. The contrast between the summer and winter profiles shows the effect of seasonal heating and cooling. During both cruises the subsurface isotherms rose abruptly, e.g. 60°F., in the vicinity of the southern limit of the Transition Zone. In winter, the northern limit of this ascent marked the beginning of the zone with little or no distinct surface layer; in summer, it marked the beginning of a very shallow surface layer with an extremely sharp thermocline. At the northern limit of the Transition Zone, the 50°F. isotherm marked the boundary of a distinct difference in the subsurface structure; to the north it marked the beginning of an area with frequent small inversions below the thermocline. The surface temperatures of both seasons showed a striking coincidence in the temperature range at which the greatest horizontal gradient occurred: on both sections inspection showed it was between 56° and 68°F. with the maximum usually occurring between 58° and 62°F. Inspection of other transects shows that this is true of all seasons of the year, both in the central and eastern Pacific (Shomura and Otsu, 1956; Graham, 1957). In spring, the zone of surface temperature discontinuity is associated with the development of the shallow thermocline and its northward advance as summer approaches. It also coincides with the southerly movement of the breakup of the shallow warm surface layer in fall and winter.

Hida (1957), in a study of the distribution of chaetognaths and pteropods in the North Pacific, found that these oceanographic divisions coincided with faunal divisions and, in fact, the term "Transition Zone" in the sense used here was introduced in his report. Jones (McGary et al., 1958), in a study of copepods, found that the formation of the warm surface layer apparently offered favorable conditions for phytoplankton blooms, followed by an increase in zooplankton standing crop. However, the latter was not characterized by a meridional advance of tropical species, but rather by the development of "blooms" of eurythermal forms such as *Calanus helgolandicus* and *C. tonsus.*

It cannot be ascertained from the data at hand whether (1) the distribution of albacore is controlled directly by surface temperature (presumably through physiological mechanisms) or whether (2) the distribution of albacore is related only indirectly to surface temperature through the seasonal march of events leading to a large standing crop of forage organisms. In rebuttal to the hypothesis of direct relationship, data from other areas do not always show the same albacore-temperature relationship, and within the survey area uniform distribution with temperature did not occur from area to area or season to season. In rebuttal to the forage hypothesis, the seasonal movement of the biological frontier coincided with the movement of the isotherms, but it did not indicate the presence of albacore in all seasons nor in all parts of the survey area.

In figure 5, the total catch of albacore is shown as the percentage of the catch made at different surface temperatures. The total catch includes all of the albacore taken by HBL in the central Pacific by troll and gill net during all seasons. For comparative purposes, similar examples from the east and west have been included. The curve shows that the central Pacific catches were made within a narrow temperature band, with a dominant mode between 58° and 60°F The overall range may be narrowed to about 55°F.-66°F., since almost all of the catches at temperatures below 55°F. were made in the fall immediately after periods having winds of Force 6 or greater and it was evident that the area had experienced a recent sharp temperature decline because of wind-induced overturn (Shomura and Otsu 1956, Graham MS[4]). The *Cobb* data are typical of the fishery which frequently develops off the coast of British Columbia, Washington, and Oregon during the late summer (Powell and Hildebrand, 1950) and indicate that the albacore occur in the same narrow temperature range as in the central Pacific. The *Jini Maru* plot was constructed from data collected in the spring live-bait fishery off Japan during a cooperative tagging program conducted in the spring of 1956 by the Japanese Fishery Agency and HEL (Van Campen and Murphy, 1957). These data are representative of this fishery. Here, the temperature range and mode are even more sharply defined than in the other two plots. These conditions

---

[4] J. J. Graham, "Macroecology of the albacore, Thunnus germo (Lacepede), in the central North Pacific" MS.

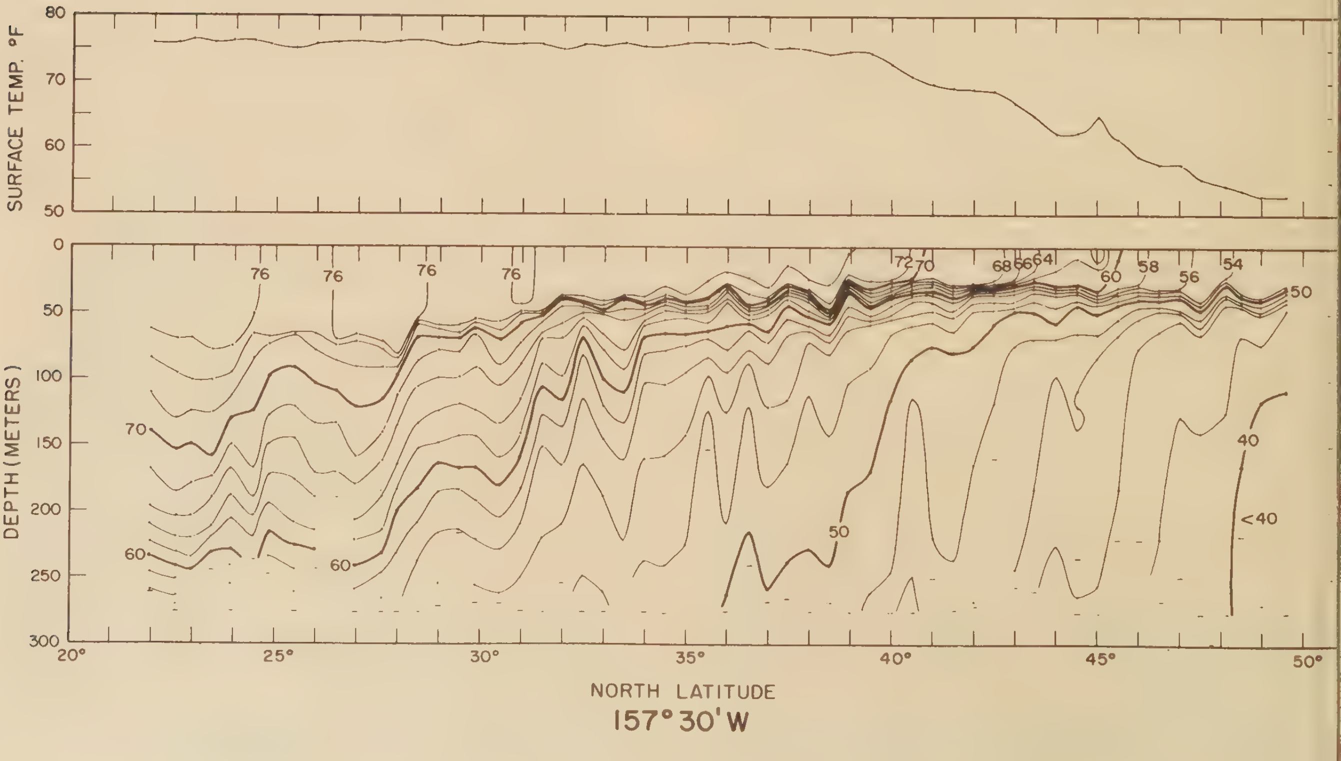


FIGURE 4b. Same along 157°30'W., *Hugh M. Smith* 30, August 1955 (McGary et al. 1958).

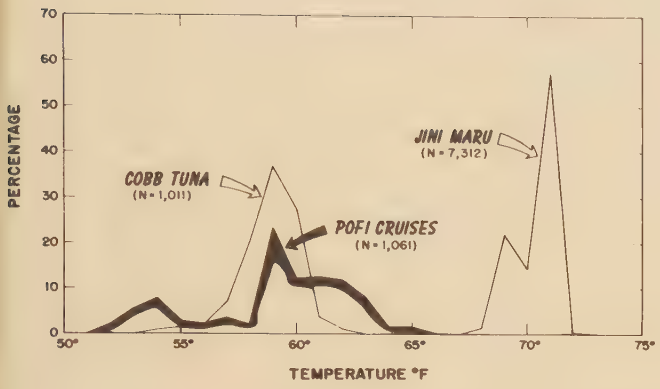


FIGURE 5. Percentage of albacore catch versus temperature of catch.

arise in part from the fact that the *Jini Maru* was engaged in commercial fishing and an effort was made to stay with the maximum concentration of fish. However, in spite of the fact that the general oceanographic features of the area indicate that the *Jini Maru* data were taken in the western extremity of the Transition Zone, the temperature range does not even overlap that of the central and eastern Pacific.

A discussion of the seasonal distribution of albacore will serve to illustrate the use and limitation of temperature as an indicator of the areas in which albacore might be expected to occur. Beginning with winter, a comparison of the catches of *John R. Manning* cruise 19 along 160°W. (fig. 6) during January 1954 with the temperature profile from *Hugh M. Smith* cruise 25 (see also fig. 4a) shows that the deep swimming albacore captured on longline gear occurred in an area having surface temperatures of 56°-66°F. and just south of the point where the largest horizontal temperature gradients occurred.

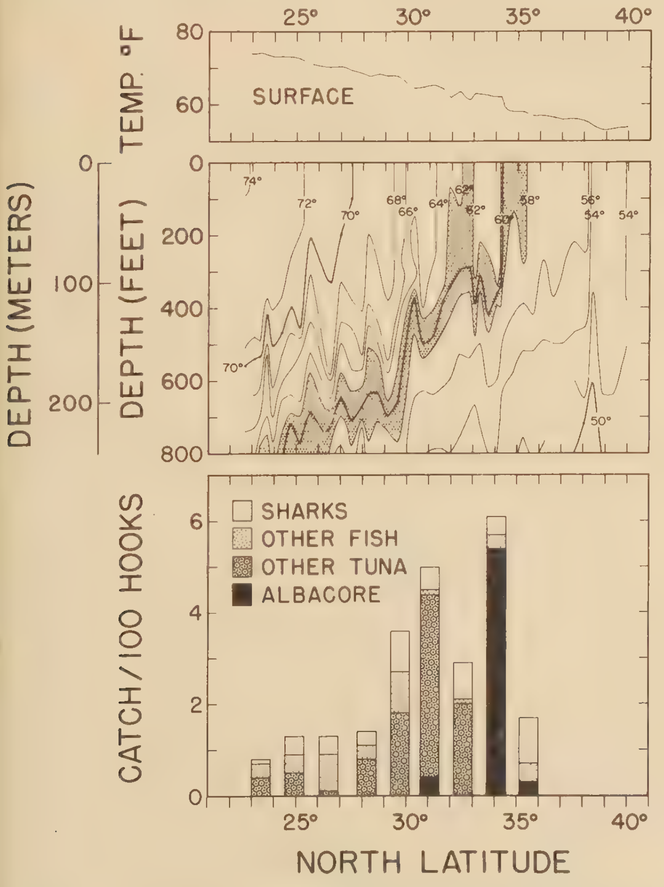


FIGURE 6. Vertical temperature profile, *Hugh M. Smith* cruise 25, January 1954 and longline catch/100 hooks, *John R. Manning* cruise 19, January 1954, along 160°W. longitude.

Figure 7 shows the winter distribution of albacore in the eastern North Pacific as indicated by the surveys of 1955 and 1956 and the Japanese winter fishery. It shows quite clearly that the latitudinal limits are almost coincident with the southern boundary of the Transition Zone (fig. 1) and the temperature front (fig. 4 and 6) and are not associated with the subtropical convergence as originally hypothesized. The dynamic topographies from the 1954 and 1955 winter cruises indicate that the subtropical convergence was in the vicinity of 24°-27°N. during both years (McGary and Stroup, 1956 and 1958). Suda (1958) also described the subtropical convergence as an area of minimal albacore catch in the western Pacific.

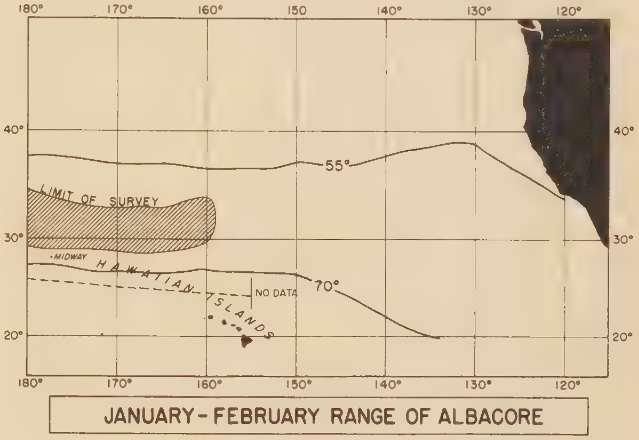


FIGURE 7. Winter distribution of albacore in the eastern North Pacific. Dashed lines indicate position of Subtropical Convergence from *Hugh M. Smith* cruises 25 (January-March 1954) and 27 (January-February 1955).

Our spring cruises (1955 and 1956) showed a conspicuous band of phytoplankton and zooplankton abundance in the 55°65°F. surface temperature range between 180° and 140°W. There was an abundance of forage organisms and a rich phytoplankton bloom was indicated by the Forel color of the water, but few albacore were caught. Only one was taken east of 170°W., and only a few scattered fish to the west of 170°W. on all three types of gear (troll, longline, and gill net).

During the fall of 1954, 1955, and 1956 albacore were taken in considerable quantities from offshore of San Francisco to 170°E. longitude, the western limit of the survey area. They were taken in waters with surface temperatures between 55°F. and 65°F., with the peak catches ocurring in the 58°-60°F. range.

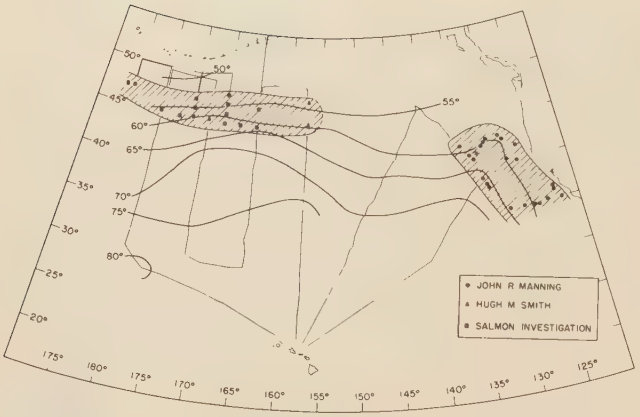


FIGURE 8. Location of albacore taken in the North Pacific by exploratory vessels, July-September 1955.

Again, this temperature appeared to coincide quite well with the biological frontier.

During the summer of 1955, because of NORPAC and the activity of the North Pacific Salmon Investigations, there was excellent coverage between 175°E. and the west coast of North America. The results showed two interesting features. Firstly, the albacore were divided into two groups, one in mid-ocean extending as far east as 155°W. (fig. 8) and the other extending northwest from the California fishery. The existence of the area of albacore scarcity has been at least partially verified in all subsequent summer surveys. Secondly, comparison of figure 4 and figure 8 shows that the mid-ocean albacore were in a shallow surface layer in Subarctic Water (figure 2) and at about the same surface temperature range as during the other seasons. The *J. R. Manning* returned to the area in 1956 and found a similar situation (fig. 9) with an even more pronounced biological frontier indicated by the plankton abundance and light penetration readings. In 1958 the 1955 and 1956 summer surveys were followed up by a commercially unsuccessful gill net effort from the chartered vessel *Paragon*. Again the fish were found in the warm layer in the southern limits of Subarctic Water, but the center was 3°-4° farther south, and the standing crops of plankton and forage were much less than observed at corresponding temperatures for the previous years.

The hydroptic charts for the mid-August period for the past four years illustrate the amount the temperature field can shift in mid-ocean and the radical changes in local temperature that result. The lower panel, figure 10, shows the variation in location of the 55° to 66°F. surface temperature band that approximates the limits of albacore distribution. As a result of such variations, annual differences of up to 10°-12°F. can occur at a given locality. This could make considerable difference in the development of the seasonal plankton cycle in the area, particularly when one considers that the average seasonal range in temperature is only 15°F. The upper panel shows the latitudinal changes in the temperature range that corresponds to the peak of the albacore abundance in the central and northeastern Pacific. It illustrates the small amount of latitudinal change necessary to produce the 10°-12°F. temperature anomalies.

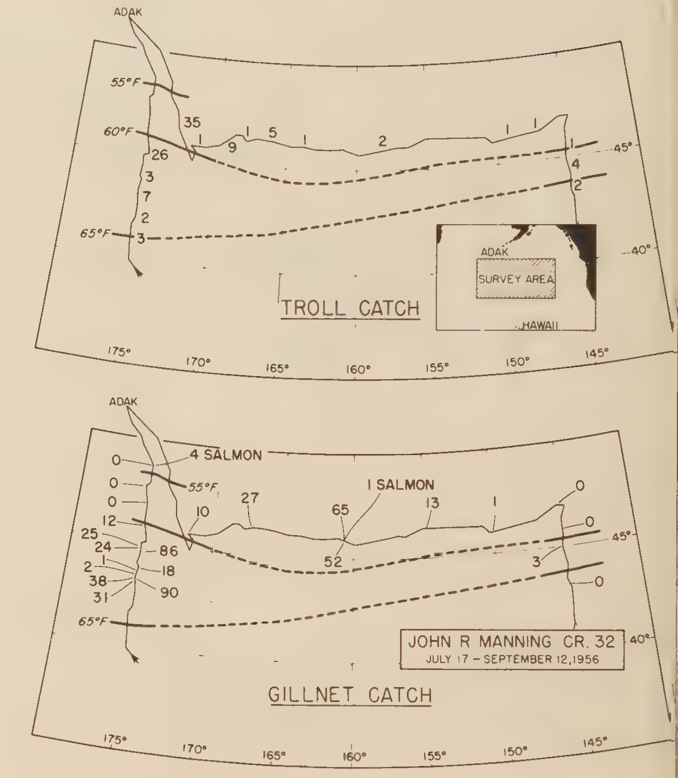


FIGURE 9. Summer 1956 albacore survey, *John R. Manning* cruise 32

The existence of a "tongue" of albacore extending northwest from the California fishery in 1955 (fig. 8) and the work of Powell and Hildebrand (1950); Powell et al. (1952), Shaefers (1951), and Partlo (1950) suggest conditions under which the Pacific Northwest fishery develops. First, albacore may be present in the summer off the northwest coast during all years but move into and concentrate in the coastal waters of British Columbia, Oregon, and Washington only when oceanographic conditions (exact nature unspecified) are favorable. Second, the extent in time and space of the coastal band of upswelling may also influence the development of the fishery and limit its shoreward extent.

During the last 10 days of July 1957, nine chartered commercial trollers and two HBL vessels made a synoptic survey of the distribution and abundance of the albacore in the coastal area between 35°N. and 47°N. The results of the survey (fig. 11) showed that these fish were present in a wide band along the coast. In the northern part of the survey area, albacore were most abundant offshore of the area of largest surface temperature gradient which indicated the outer limit of the band of upwelling (fig. 12). However, their distribution was far from continuous and was not completely associated with any feature of the boundary, such as the tongues of relatively warm water which penetrated shoreward.

The radical annual temperature differences shown in hydroptic charts of the coastal areas (fig. 10) might

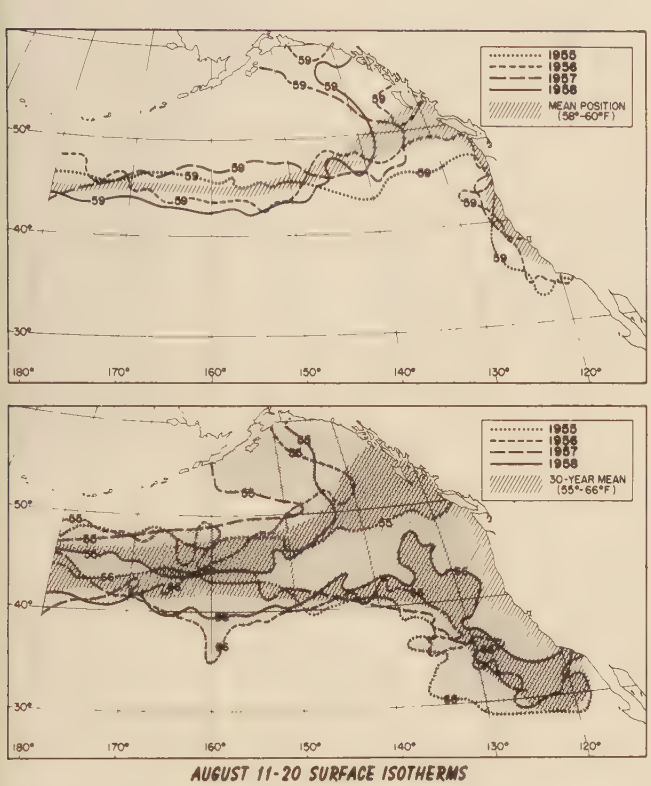

1955
1956
1957
1958
MEAN POSITION (58°-60°F)
30-YEAR MEAN (55°-66°F)
50°
40°
30°
180°
170°
160°
150°
140°
130°
120°
AUGUST 11-20 SURFACE ISOTHERMS

FIGURE 10. LOWER PANEL—mid-August mean and 1955 through 1958 positions of the 55° and 66°F. isotherms; UPPER PANEL—mid-August mean and center of the 58°-60°F. isotherms for 1955 through 1958.

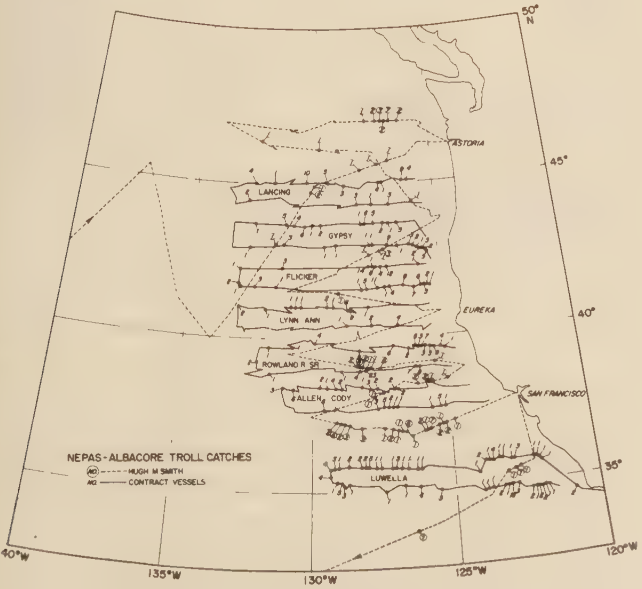

50° N
ASTORIA
45°
LANCING
GYPSY
FLICKER
LYNN ANN
EUREKA
40°
ROWLAND R SR
ALLEN
CODY
SAN FRANCISCO
NEPAS-ALBACORE TROLL CATCHES
HUGH M SMITH
CONTRACT VESSELS
LUWELLA
35°
140°W
135°W
130°W
125°W
120°W

FIGURE 11. NEPAS (Northeastern Pacific Albacore Survey) troll catches, July 1957.

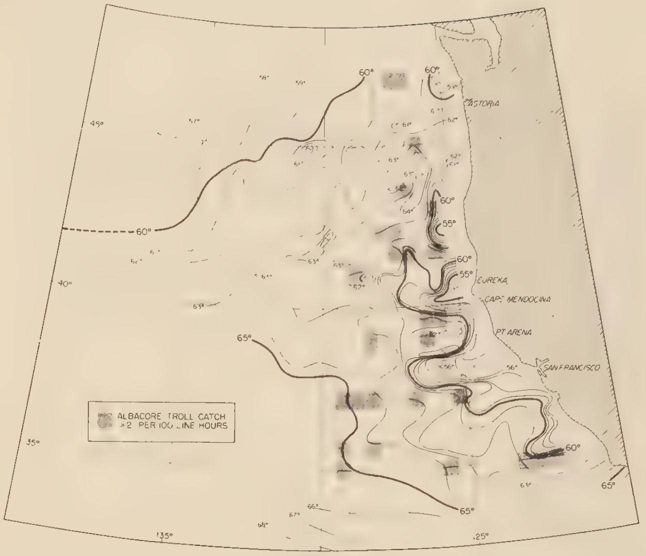
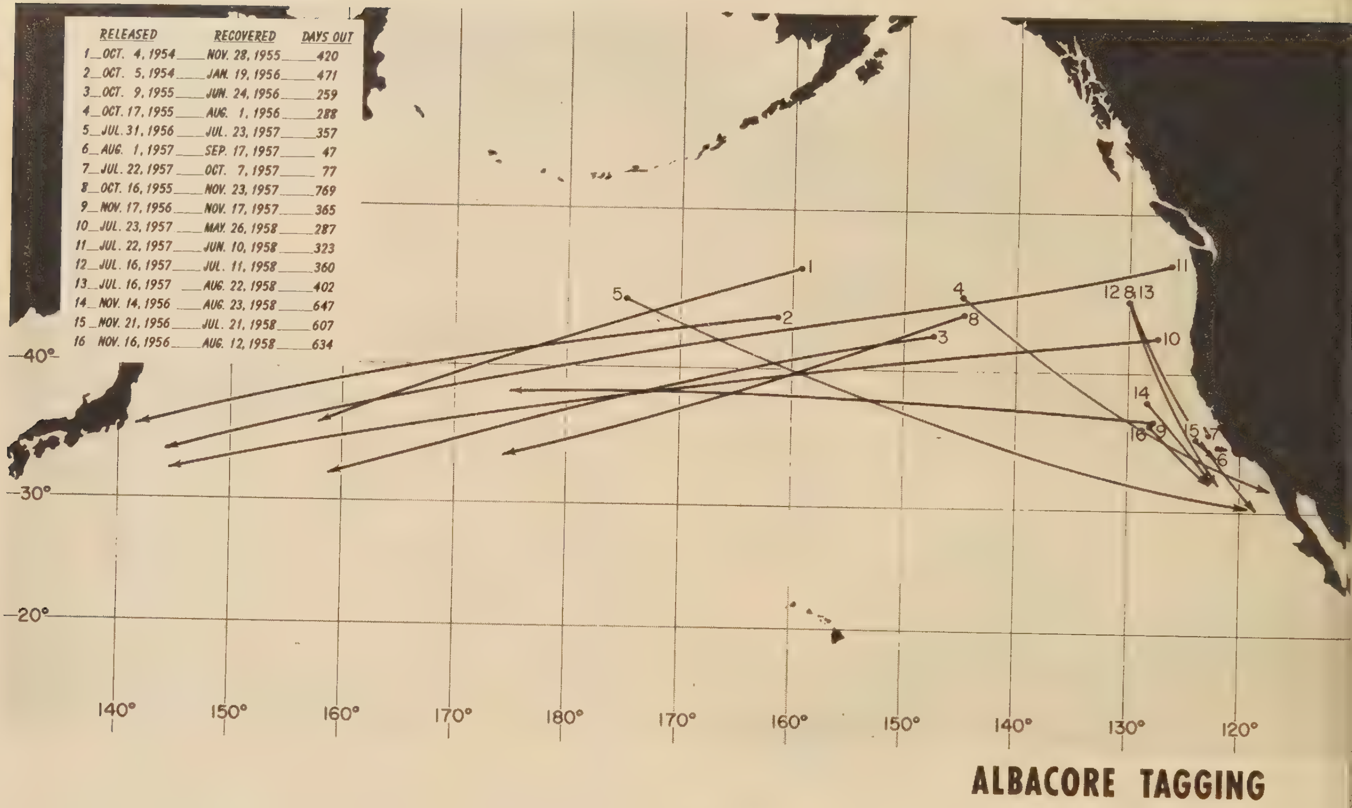

ASTORIA
EUREKA
CAPE MENDOCINO
PT ARENA
SAN FRANCISCO
ALBACORE TROLL CATCH >2 PER 100 LINE HOURS
60°
65°
45°
40°
35°
135°
125°

FIGURE 12. NEPAS surface temperatures and best albacore catch rates.

also account in part for the yearly fluctuations in the landings of the California fishery as well as the radical fluctuations in the Pacific Northwest fishery. The charts show that suitable temperature conditions for albacore may in some years occur as far north as Kodiak Island and lend credence to reports of albacore in the Gulf of Alaska in 1957 and 1958.

Not all of our efforts have been confined to exploratory fishing work. Results from our tagging experiment, literature research, and age, growth, and spawning studies have given us a reasonably plausible picture of albacore migration routes in relation to oceanographic features. One thousand two hundred and six albacore have been tagged. In addition, we have helped establish a tagging experiment in the Japanese live-bait fishery. Figure 13 shows the points of release and recapture of our 16 returns. It shows migration from the mid-ocean area to both the American and the Japanese fisheries and movement from the American to the Japanese fishery. Recoveries from California Fish and Game tag releases (Ganssle and Clemens 1953) also show this latter movement. Japanese tag returns (K. Mimura, personal communication) have shown rapid easterly movements within their spring live-bait fishery. On the basis of these returns, the oceanography, our spawning and growth studies (Otsu and Uchida, 1959a and b), and Suda's (1958) paper on migration within the Japanese fishery, we have arrived at the somewhat incomplete pattern of albacore migrations shown in figure 14. Here we show an easterly spring and summer migration along the 55°-65°F. temperature frontier in the Transition Zone and a westward migration along it in the fall and winter. The lack of an apparent connective link between the two segments of the eastern migration may be because the Japanese tagging experiment has only begun recently. Also, their tagging has been primarily in their live-bait fishery, which, in general, takes larger fish than the American west coast fishery. The postulated spawning area is located



RELEASED	RECOVERED	DAYS OUT
1_OCT. 4, 1954	NOV. 28, 1955	420
2_OCT. 5, 1954	JAN. 19, 1956	471
3_OCT. 9, 1955	JUN. 24, 1956	259
4_OCT. 17, 1955	AUG. 1, 1956	288
5_JUL. 31, 1956	JUL. 23, 1957	357
6_AUG. 1, 1957	SEP. 17, 1957	47
7_JUL. 22, 1957	OCT. 7, 1957	77
8_OCT. 16, 1955	NOV. 23, 1957	769
9_NOV. 17, 1956	NOV. 17, 1957	365
10_JUL. 23, 1957	MAY. 26, 1958	287
11_JUL. 22, 1957	JUN. 10, 1958	323
12_JUL. 16, 1957	JUL. 11, 1958	360
13_JUL. 16, 1957	AUG. 22, 1958	402
14_NOV. 14, 1956	AUG. 23, 1958	647
15_NOV. 21, 1956	JUL. 21, 1958	607
16 NOV. 16, 1956	AUG. 12, 1958	634

FIGURE 13. Chart of points of release and return of tagged albacore.

in the North Equatorial Current and is based on studies of albacore landed in the Hawaiian longline fishery as well as on HBL's exploratory cruises and data from the Japanese longline fishery in the west.

REFERENCES

Ganssle, D., and H. B. Clemens, 1953. California-tagged albacore recovered off Japan. *California Fish and Game* 39(4) : 443.

Graham, J. J., 1957. Central North Pacific albacore surveys, May to November 1955. *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 212*, 38 p.

Hida, T. S., 1957. The chaetognaths and pteropods as biological indicators in the North Pacific. *U.S. Fish and Wldlife Service, Special Scientific Report—Fisheries No. 215*, 13 p.

Masuzawa, J., 1957. A contribution to the knowledge of the Kuroshio east of Japan. *The Oceanographic Magazine* 9(1) : 21-34.

McGary, J. W., and E. D. Stroup, 1956. Mid-Pacific oceanography, Part VIII, middle latitude waters, January-March 1954, *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 180*, 173 p.

1958. Oceanographic observations in the central North Pacific, September 1956-August 1955, *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 252*, 250 p.

McGary, J. W., E. C. Jones, and J. J. Graham, 1958. Enrichment in the Transition Zone between the Subarctic and Central Water masses of the central North Pacific. *Proceedings of the 9th Pacific Science Congress, 1957*, 16: 82-89..

Otsu, T., and R. N. Uchida, 1959a. Sexual maturity and spawning of albacore in the Pacific Ocean, *U.S. Fish and Wildlife Service, Fishery Bulletin 59* (148) : 287-305.

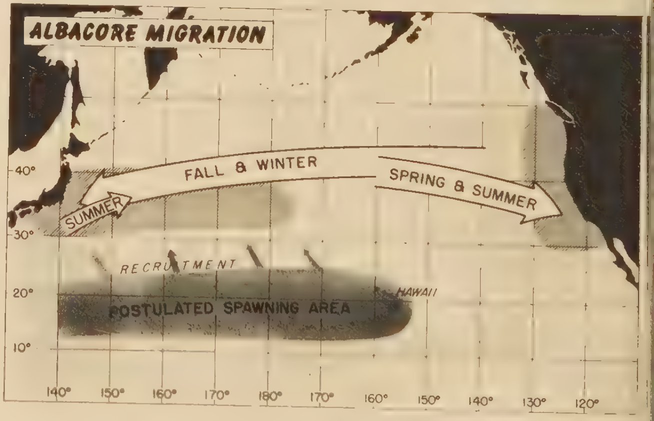


FIGURE 14. Albacore migration.

1959b. Study of age determination by hard parts of albacore from central North Pacific and Hawaiian waters, *U.S. Fish and Wildlife Service, Fishery Bulletin 59* (150) : 353-363.

Partlo, J. M., 1950. A report on the 1949 albacore fishery *(Thunnus alalunga). Fisheries research Board of Canada, Circular No. 20.*

Powell, D. E., and H. A. Hildebrand, 1950. Albacore tuna exploration in Alaskan and adjacent waters, 1949. *U.S. Fish and Wildlife Service, Fishery Leaflet 376*, May.

Powell, D. E., D. L. Alversen, and R. Livingstone, Jr., 1952. North Pacific albacore tuna exploration, 1950, *U.S. Fish and Wildlife Service, Fishery Leaflet 402*, April.

Shaefers, E. A., 1953. North Pacific albacore tuna exploration, 1952, *U.S. Fish and Wildlife Service, Commercial Fisheries Review* **15**(9) : 1-6.

Shomura, R. S., and T. Otsu, 1956. Central North Pacific albacore surveys, January 1954-February 1955, *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 173*, 30.

Suda, A., 1958. Recruitment and dispersion of the North Pacific albacore. *Report of Nankai Regional Fisheries Research Laboratory, No. 9.* (Translation by G. Y. Beard)

Sverdrup, H. W., M. W. Johnson, and R. H. Fleming, 1942. "The Oceans, their Physics, Chemistry, and General Biology." Prentice Hall, Inc., 1087.

Uda, M., 1943. On the structure of the boundary zone of different water masses. *Journal of the Oceanographic Society of Japan* **2**(4).

Van Campen, W. G., and G. I. Murphy, 1957. Tagging albacore on a Japanese bait boat. *Pacific Fisherman* **55**(3) : 37, 39, 41-43.

Wilson, R. C., 1953. Tuna marking, a progress report. *California Fish and Game* **37**(4).

Greatest Not Always Best

The *greatest* catch is not necessarily the *best* catch, and the optimum level of exploitation can only be determined by careful weighing of the capacity of markets to absorb the catch and of the effect of the production on the fishermen and on others whose welfare is affected.

Finally, the fish meal situation illustrates what is becoming increasingly clearer in all areas of human activity: What affects people in one country leaves its mark on a large part of the rest of the world. When overproduction of fish occurs in Lima, its impact is felt in Provincetown, in Hamburg, in Reykjavik, and in Capetown.

In affairs of state, we must cooperate and negotiate internationally if we are to survive.

Attention All Whale Watchers!

Cooperation on the part of a hotel owner at Fenwick, Delaware, enabled Dr. Charles O. Handley, Jr., of the division of mammals, Smithsonian Institution, to see and identify a rare species of small whale which had washed ashore on the hotel beach. Because the odor of the dead whale was not helping the hotel's business, the manager had hired a bulldozer to bury it. But he agreed to delay the burial until Dr. Handley could dash over from Washington.

The whale proved to be a *Ziphius cavirostris,* or Cuvier's beaked whale. Dr. Handley hastily measured it, and removed the head, which he took back to the National Museum for further study.

Dr. Handley is a member of the Committee on Marine Mammals of the American Society of Mammalogists. This committee is attempting to record all strandings of whales, porpoises, dolphins, seals, etc., on the coasts of North America. Anyone who sees or hears of a stranding of one of these animals is urged to get in touch with Dr. Handley, at the Smithsonian, Washington, D. C.

Add Scallops to Rockets

Cape Canaveral, the name almost synonymous with giant rockets and space missiles, now has another claim to fame. A huge stock of calico scallops *(Pecten gibbus),* apparently more extensive than any previously known scallop bed in the world, has been discovered along the east coast of Florida, within sight of the gantry towers and launching pads of Canaveral. Commercial concentrations were found over a 1,200-square-mile area by the *Silver Bay,* U. S. Fish and Wildlife research vessel, with indications that the bed might be even more extensive.

Power From The Tides

By J. L. McHUGH

Chief, Division of Biological Research
Bureau of Commercial Fisheries
Washington, D. C.

FOR HUNDREDS of years man has recognized the tides as a potential source of power, but his efforts to harness these forces have been notably inefficient. We know that tidal power was used to grind grain as early as the eleventh century; and that in the eighteenth and early nineteenth centuries many tide-mills were built in England and America. Some of these simply used a fraction of the tidal forces directly; the more advanced types, such as "Slade's Mill," built in 1734 at Chelsea, Massachusetts, stored power behind a dam; but none generated more than 100

HARVESTING FISH FROM A CART. *At Minudie, on the shores of the Bay of Fundy, fishermen gather their catch from horse-drawn carts when the enormous tide goes out and leaves fish trapped in gill nets high in the air. (Nova Scotia Film Bureau)*

horsepower, an insignificant fraction of the total energy available.

The development of electricity focused attention on the more easily controlled sources of power in rivers, and vast hydroelectric projects now utilize much of the energy available in many of our largest streams. But man has never failed to dream about taming the infinitely greater power of the tides, and his imagination has been stimulated rather than discouraged by the difficulties that have impeded his progress.

Tides Not Easily Harnessed

Why should it be so difficult to capture the forces of the tides? The answer is relatively simple, but the engineering and social problems are immense. The amount of power generated by a hydroelectric project depends upon the amount of water flowing, and the height, or head, from which it drops. The rise and fall of the tides in most parts of the world are slight compared with the difference in water level in most conventional hydroelectric projects, and the enormously large quantities of water needed to offset the relatively small head available from tidal movements usually prohibits such projects.

A few places in the world, however, have tides great enough for practical purposes, and none is more favorable in this respect than the famous Bay of Fundy, the home of the world's largest tides. Serious efforts to harness Fundy's tides have been underway for about forty years, but opinion still is divided as to the economic feasibility of such a project.

First Plant in France

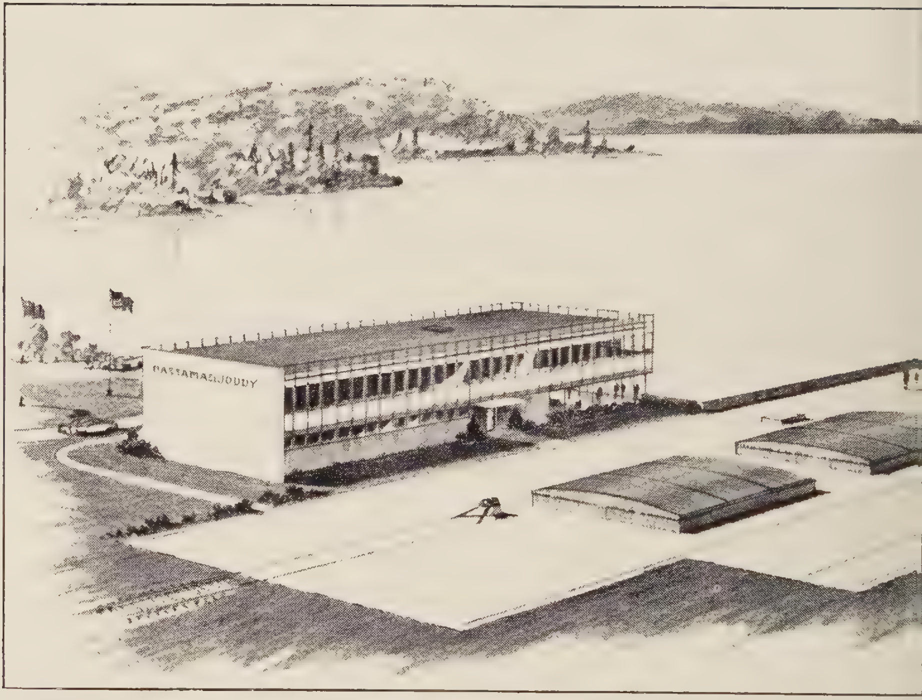
Feasibility studies for large tidal power plants have also been made in the estuary of the Severn River, in England; L'Aber Vrach Bay and Mont St. Michel in France; and San José Gulf in Argentina. But the first large-scale tidal power plant in the world may be built on the estuary of La Rance River, on the coast of Brittany in France, where certain components are already being tested.

Formidable difficulties face the tidal power engineer. The direction of flow reverses twice a day, and with it the available energy fluctuates, from zero at the moment of reversal, or slack water, to a maximum at full flood or ebb. Even more distressing are the changing times of high and low tide each day, caused by the fifty-minute difference in period of orbit of earth and moon; and the regular fourteen-day variations in the relative positions of earth, moon, and sun. Thus, any power project that depends upon the tides will be a fluctuating source of power, and the fluctuations will be linked neither with time of day nor with season—certainly not with the fluctuating demands of the users of electricity.

Zero Twice a Day

Any power project must produce benefits that clearly exceed the costs of construction and operation, otherwise it cannot be justified economically. The hydroelectric project of today, furthermore, must be able to guarantee a certain level of power production, if it is to attract customers.

The principle of the old-fashioned



ARCHITECT'S SKETCH *of the proposed Passamaquoddy Power House at Moose Isla*
which has the greatest extremes of tide in the world. Several sources of auxiliary

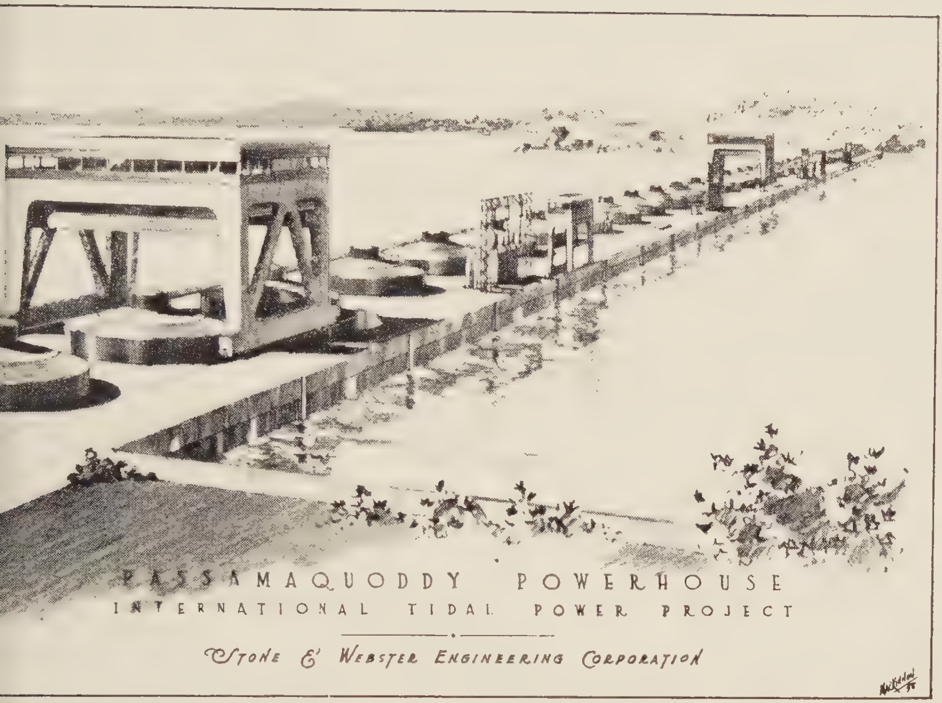
tide-mill would be of no interest to modern industry, for the power produced would fluctuate constantly and would reach zero about twice a day. The difficulties that have stifled use of this power source are related to the problem of creating uniformity in power output. Many methods are known, but only the major types need be considered here.

The simplest type of improvement over the direct-drive method is to place a dam across an arm of the sea, creating a reservoir which can be filled at high tide and drained at low. Various methods can be used to increase the efficiency of such a system, but even the best of these will leave periods in which no power can be generated.

A better arrangement is to create two pools, one of which is filled at high tide, the other of which is closed at low. A continuous, though variable, flow of water in one direction can be maintained from the high to the low pool.

Several arrangements of pools and power units are possible, and the best of these produce power continuously, but power output is variable. Even the most favorable plan produces twice as much power at certain tidal stages as at others.

The guaranteed power output of purely tidal projects, therefore, coin-


PASSAMAQUODDY POWERHOUSE
INTERNATIONAL TIDAL POWER PROJECT
Stone & Webster Engineering Corporation

It would generate electricity from tides that daily rush in and out of the Bay of Fundy, ge and supply have been considered by engineers. (U.S. Army Corps of Engineers)

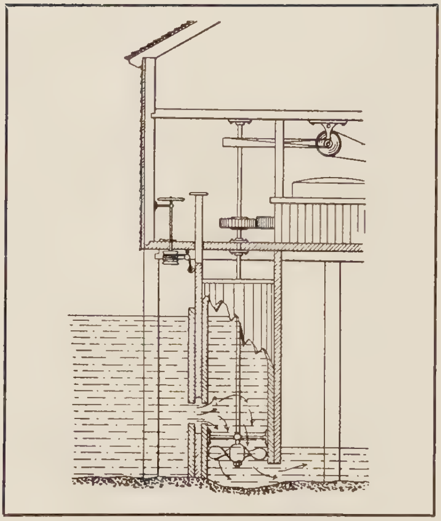
cides with the minimum, and this is neither efficient nor economically sound. The obvious answer is to provide an auxiliary source of power, which can act somewhat as a storage battery, building up power when the tidal output is high, and supplementing lower levels of output.

Passamaquoddy Investigations

The criteria for selection of a site for such a project depend upon topography as well as on tidal rise and fall. The upper end of the Bay of Fundy, where tides are highest, has been considered as a possible site by Canada, but the region that has received greatest attention is near the lower end, lying athwart the eastern end of the boundary between Canada and the United States.

Passamaquoddy Bay, almost entirely in Canada, and Cobscook Bay in the United States, have been under serious consideration since 1919, when a private organization, Dexter P. Cooper, Inc., was granted permission by the two governments to investigate, and possibly construct, a power project. Adverse effects upon the fisheries predicted by Canadian scientists and failure to obtain loans to support a purely United States project caused the project to fail.

Revival of active interest in the project undoubtedly arose through the



HOW TIDE MACHINERY OPERATES. *This simple diagram shows how an incoming tide used its power against a turbine, which turned a shaft geared to the mill's various operations. An outgoing tide reversed the mechanism. All operations ceased when the tide was at full flood or ebb. (From* The Spice Mill on the Marsh, *by Thomas P. Smith. Courtesy D. & L. Slade Co., and Chamber of Commerce, Chelsea, Mass.)*

efforts of the late President Franklin D. Roosevelt, who spent his summers on Campobello Island and was impressed with the potentiality of 'Quoddy to provide an assured source of cheap power for New England and New Brunswick. He was not able to arouse interest in Canada for an international project, and so it was decided to begin in a small way to develop a single-pool project entirely within United States territory.

The President hoped that Canada might be more interested in the proposal once work began. The depression of the 1930's also gave justification for the project, for it provided work in a seriously distressed area. This social-welfare aspect led some people to doubt the economic soundness of the international plan. In the late 1930's the United States Army Corps of Engineers commenced construction and built three dams, which still exist, forming highway links from the mainland to Eastport, Maine, and separating Cobscook Bay from Passamaquoddy Bay. But the project was abandoned long before completion because Congress did not continue to appropriate funds.

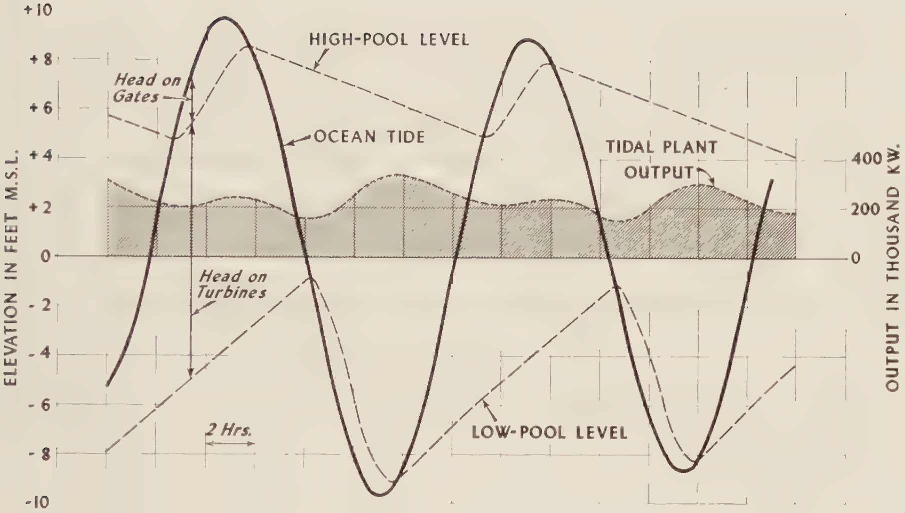
Referred to Two Boards

In 1956 the Governments of Canada and the United States referred the problem to the International Joint Commission. The Commission appointed two Boards to study the question, the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board.

The work of these Boards was completed late in 1959, and the Board members briefed the International Joint Commission in Boston, Massachusetts, in January, 1960, explaining the engineering, economic, and fishery aspects of the problem.

Fisheries of the 'Quoddy Region

Herring is the most important commercial fish species in the area, but cod, haddock, flounders, redfish, hake, pollock, salmon, alewives, smelt, clams, scallops, and lobsters also contribute to the fishery harvest. Landings of "sardine" herring at United States and Canadian ports from the 'Quoddy region have fluctuated about an average of fifty-five mil-



TYPICAL TIDAL PLANT OPERATION. *Reduced to a chart, here is how the cycle of tides, pool levels, and power output looks to an engineer. Each square (horizontally) represents two hours of time; (vertically) two feet above or below mean sea level. (U.S. Army Corps of Engineers)*

lion pounds annually, worth nearly a million dollars at current dockside prices. In the processed form, this annual catch is sold for about five million dollars.

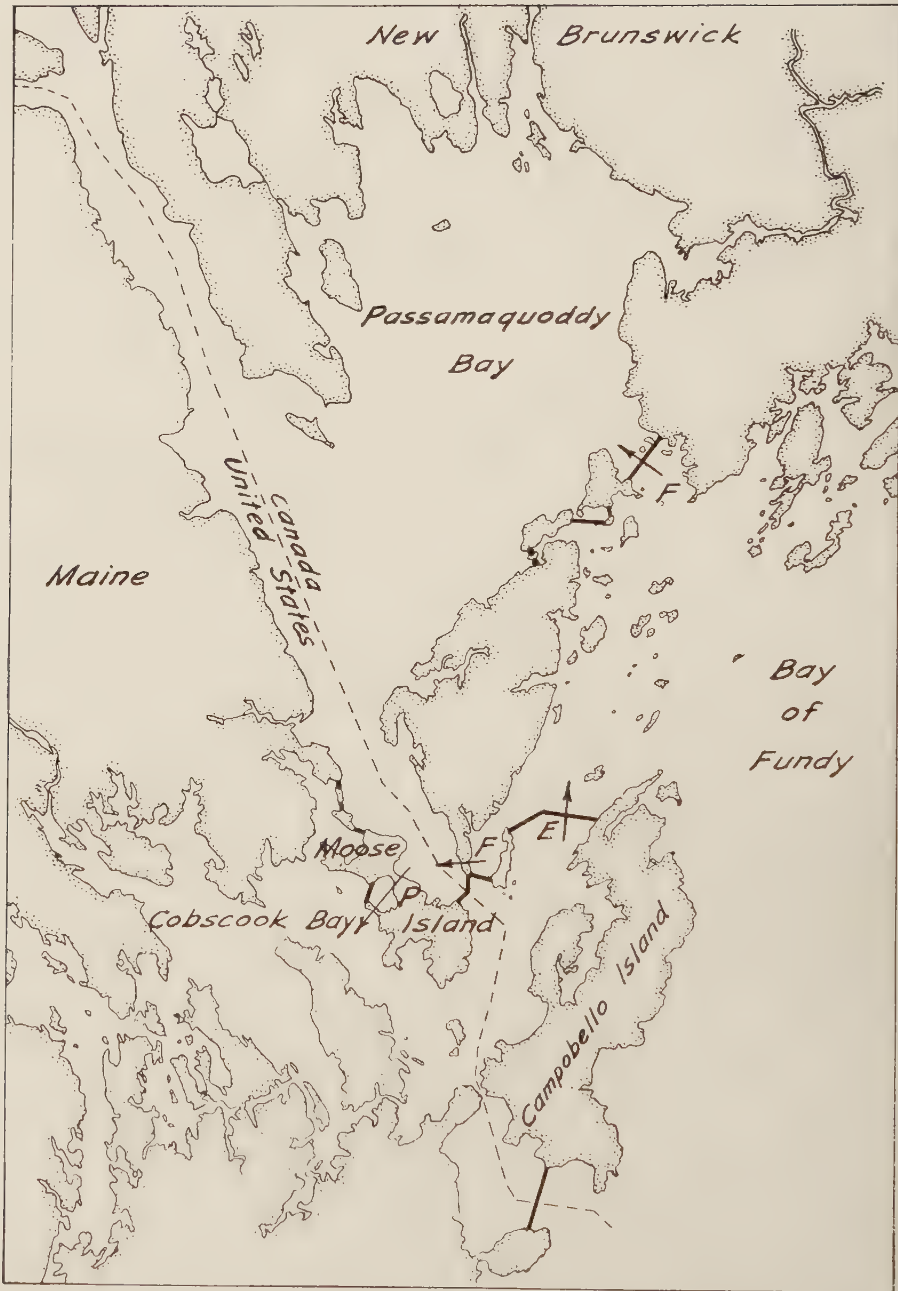
Considerable quantities of herring also are canned as pet food, and some are processed as fish meal, oil, and solubles. Almost eleven million dollars worth of herring products were produced in 1957 in the United States part of the Passamaquoddy region. In both countries herring have made up slightly over 50 per cent of the total value of fishery landings in 'Quoddy in the past ten years. Salmon and trout also are sought by sport fishermen.

Recent Evaluation of Project

The Fisheries Board made extensive investigations of the oceanography and fisheries of the region and concluded that although pronounced environmental changes would take place within the impoundments, the total effect upon the fisheries would be slight, and no significant effects would be felt beyond the immediate influence of the dams and gates. It was predicted that some fisheries would suffer, others would benefit, and still others would be unaffected.

If the project is authorized and constructed, a check on the accuracy of these predictions will be of inestimable value to fishery science everywhere, for it will test our knowledge of the effect of environment changes on marine animals.

Mean water level will be raised about 6 feet in Passamaquoddy Bay and lowered about 5 feet in Cobscook Bay. Current patterns within these bays also will be altered substantially,

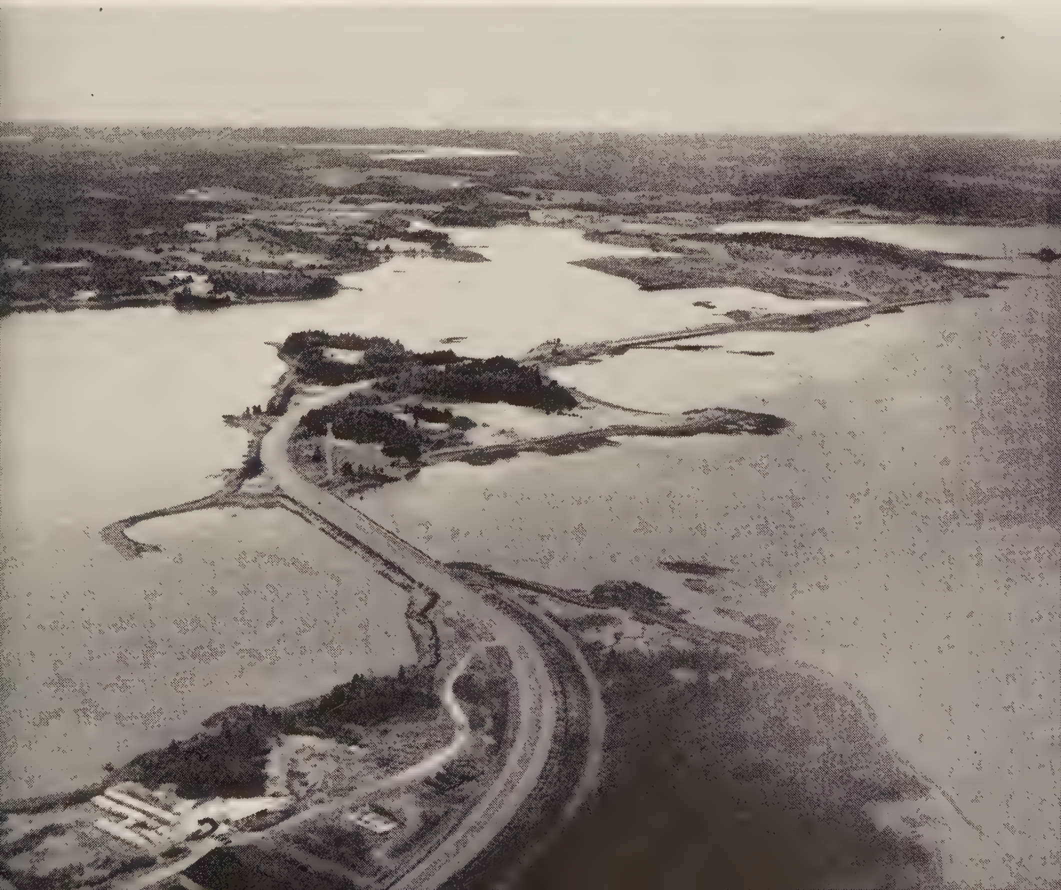

New Brunswick
Passamaquoddy Bay
Canada
United States
Maine
F
F
E
P
Moose Island
Cobscook Bay
Bay of Fundy
Campobello Island

TWO NATIONS WOULD SHARE *the benefits of the International Tidal Power Project, and two bays. Passamaquoddy and Cobscook, would be dammed to form high and low pools. Filling gates are designated by "F", emptying gates by "E", and the power unit by "P." Locks would also be provided. (Map from author)* for the emptying and filling gates will be closed during about three quarters of each tidal cycle. The diminished velocities will reduce vertical mixing of the water, causing increased stratification, with reduced salinity in the surface layers. This will increase the possibility of ice cover in winter, and will increase surface water temperatures in summer.

Herring found in the 'Quoddy region are part of a large population that is widely distributed throughout the Bay of Fundy and the Gulf of Maine, hence damage to the herring fishery is expected to be indirect, caused by the need to relocate some weirs, to lengthen stakes on some to allow for increased water depth, and perhaps to replace weirs more frequently because wood-borer activity may increase. Damage to the lobster fishery also will be indirect, caused by the need to relocate lobster pounds, refrigerate water, or extend intake pipes, to compensate for higher surface water temperatures.

The clam fishery will be affected most seriously, for changes in water levels will produce drastic changes in

THIS MUCH IS COMPLETED. *Dams or causeways built in the 1930's by the U.S. Army Corps of Engineers link Eastport, Maine, with the mainland. While they separate Passamaquoddy (right) and Cobscook (left) Bays their principal use today is for a highway. Eventually they could be worked into the tidal power project. (U.S. Army Corps of Engineers)*



"PACKED LIKE SARDINES IN A CAN" *is an old expression, and these women in a Maine sardine cannery show how it is done, with skill and dispatch. Maine sardines are somewhat larger than most of the imported species, and are a meal rather than a tidbit. Total effect of the proposed dams upon the fishing industries of the 'Quoddy region such as sardine canning would be slight, it is estimated. (Richard Merrill, Melrose, Mass.)*

the environment. This will reduce the clam population to a very low level for a few years until new populations can become established farther up the beaches on Passamaquoddy grounds, lower down in Cobscook Bay. At the new water levels suitable bottom for clams will be reduced in area, hence the clam resource is not expected to regain its present level of production.

To balance this and other losses it is predicted that conditions for certain other species, such as winter flounders, scallops, lobsters, and anadromous fishes like salmon, alewives, shad, and striped bass will improve.

Will Balance Out

If compensation is provided for indirect damage to fishing installations, it is not expected that the fisheries as a whole will suffer, for losses and gains in biological productivity will balance.

WEIRS TRAP UNWARY HERRING. *This important fishery would be only indirectly affected by tidal dams. Herring do not spawn in the 'Quoddy region, but move in as young. Some weirs would have to be relocated; others would have to have stakes lengthened to allow for increased water depth. (Courtesy Dr. J. L. Hart)*

The Engineering Board evaluated various modifications of the one- and two-pool plans and recommended a scheme in which Passamaquoddy Bay would be dammed to form a high pool, Cobscook Bay would be enclosed to form a low pool, and the powerhouse would discharge from the high to the low pool.

Several sources of auxiliary power storage and supply were considered, such as the one which would require pumping of Passamaquoddy Bay water into a reservoir created by damming the Digdeguash River estuary, at the northern end of Passamaquoddy Bay, another of which would place a conventional hydroelectric dam across the Saint John River at Rankin Rapids. The Rankin Rapids site was judged most efficient economically. Total costs, including several alternative auxiliary power sources, have been estimated at 277 to 337 million dollars for the United States share and 289 to 315 million dollars for Canada.

Approval of the project will depend on many things. Ultimately, of course, the decision will be made on the basis of economic gain. It is by no means certain that the various factions: industry, commercial fisheries, sport fishermen, lovers of wilderness areas, and politicians, will reach agreement on the ratio of benefit to cost. Whatever the result, however, the Passamaquoddy project will remain a monument to man's imagination and to his urge to put one of the most powerful forces of nature to useful work.

AUTHOR'S NOTE: As this article goes to press, a news item datelined St. Malo, France, appeared in the *Washington Post* on January 8, 1961. The release states that a prototype of a combination turbo-generator and pump, known as a "bulb unit," installed in a lock is producing 12,500 horsepower from tidal forces. It is said that this unit is over 90 per cent efficient when used as a turbine and over 70 per cent efficient when used as a pump. This combination of operations solves a principal difficulty in harnessing the tides; namely, that it compensates for the lack of phase between tidal cycles and peak power demand.

New Mariners Atlases

To the ordinary layman a marine atlas, giving data on average currents and weather conditions in certain areas of the sea, does not make for very exciting reading. But to all those who sail the high seas, whether they be professional mariners or amateur yachtsmen, such publications are invaluable.

The last in a series of five British atlases, giving the world-wide coverage of the oceans, has just been released by the Marine Division of the British Meteorological Office. Numbered M.O. 655, it is entitled: "Quarterly Surface Current Charts of the Eastern North Pacific Ocean."

The charts have been compiled from observations of surface currents reported to the Meteorological Office by volunteer marine observers in British merchant ships (*Sea Frontiers*, Vol. 5, No. 3, "Meteorology and the Sea," by C. E. N. Frankcom), and from observations made in H.M. ships and forwarded by the Hydrographer of the Navy.

These charts are similar, but more detailed and cover a longer period of time (1855-1952) than those issued by the U. S. Hydrographic Office, and by German and Japanese government agencies. The British operate more merchant ships and therefore are in a position to give more complete reports. The charts are not designed solely for British pilots, however, and, with the increasing exchange of such information, sea atlases are becoming more and more alike.

Woods Hole Series

Almost simultaneously, Woods Hole Oceanographic Institution announces a new series of oceanic atlases with the launching of Volume One, "The Atlantic Ocean Atlas of

STOMACH CONTENTS OF THE BERING SEA KING CRAB

by

Patsy A. McLaughlin and James F. Hebard
Biological Laboratory, Bureau of Commercial Fisheries
Seattle, Washington

ABSTRACT

This preliminary study of the stomach contents of the Bering Sea king crabs indicates that the major food items of these crabs are molluscs and echinoderms. The frequent occurrence of echinoderms in the stomachs in large amounts is in contrast to the findings of Russian workers who feel that echinoderms play only a very minor dietary role in the king crabs of the Kamchatka region. Differences in food preferences apparently do not exist between the sexes.

This report is the result of the analysis of king crab stomachs collected during the summer of 1957 in southeastern Bering Sea by biologists of the King Crab Investigation of the United States Fish and Wildlife Service. A study of the food habits of the crab is of considerable importance because food availability and utilization may play important roles in the distribution, migration and molting patterns of the crabs.

Very few reports on the food habits of the king crab, *Paralithodes camtschatica* (Tilesius), are found in the literature. Among the available papers, the work of Feniuk (1945) is the most recent and perhaps the most complete. For the most part, his methods were used in this analysis. Quantitative studies on the species of food of the crab are made exceedingly difficult because, in contrast to fish which for the most part swallow food whole, the crab breaks up his food with the chelae before ingesting it; hence reconstruction of individual organisms is usually impossible. Methods which are used in quantitative food studies of vertebrates which masticate their food are not adaptable to the food studies of crabs, since the quantity of crab stomach contents is usually small. As yet, no suitable method of quantitative analysis of these stomach contents has been devised.

Because of this lack of an applicable method, the smallness of samples from any one area and the limited scope of available related data, this report intends primarily to indicate the types of organisms which contribute to the diet of crabs. However, it will show quantitatively the fullness of the stomachs examined. More intensive studies, designed to compensate for the inadequacies noted here, will be pursued in 1958.

The crabs from which stomach samples were taken were from catches made by the chartered trawler *Mitkof* during the months of June and July, 1957 (Figure 1). Of the 329 stomachs obtained, the sexes were almost equally represented—160 females and 169 males. Sizes ranged from 63 mm. to 193 mm. in carapace length. All types of presently recognized shell conditions were also represented, as the samples varied from newly molted, soft-shelled crabs to those having barnacle-encrusted, very old shells. The majority of the crabs, however, possessed hard new shells, indicating a molt within the season.

Anatomically, the stomach of the king crab is divided into two sections, referred to as the cardiac and pyloric sections (Marukawa, 1933). This conventional nomenclature will be used in this report. However, as pointed out by Pearson (1908), these terms may technically be misnomers when applied to the Malacostraca, since the cardiac section of the stomach is

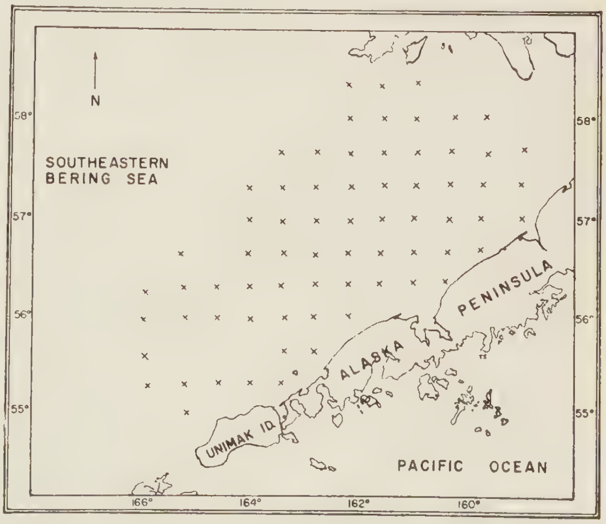


FIGURE 1. Stations at which stomach samples were taken during 1957.

Received for publication August 18, 1959. Original, English.
Source: Contribution from the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, SSR-F 291. INPFC Document No. 280.
Bulletin 5, Int. North Pac. Fish. Comm., August, 1961.

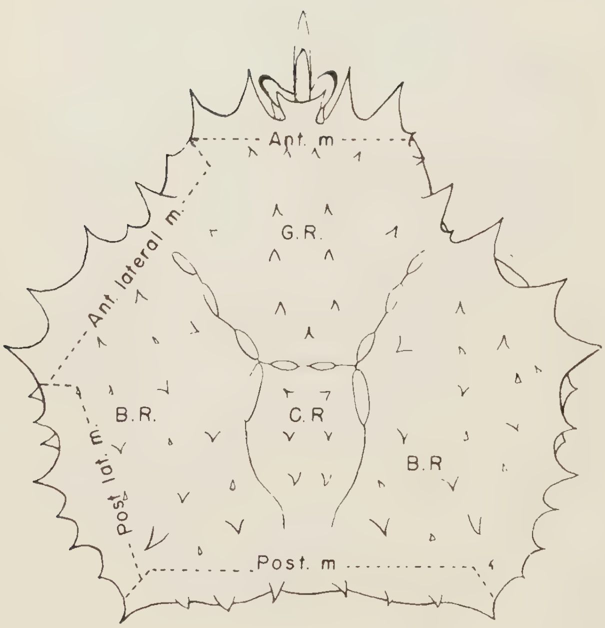


FIGURE 2. Carapace of king crab (after Marukawa).
G.R., Gastric region ;
C.R., Cardiac region ;
B.R., Branchial region.

farthest from the heart and lies under the region of the carapace defined as the gastric region (Figure 2) by Marukawa (1933). Figure 3 shows the position of the stomach with relation to the carapace and the rest of the body.

The cardiac section of the stomach was dissected out of each crab and preserved in 4 per cent formalin in an individual cloth bag. The pyloric section and the intestine were not used in this study. Anatomically, the cardiac section of the stomach is divided into two parts. The anterior part, which comprises the largest area of the entire stomach, is guarded at its entrance by a hairy filter and at its exit by the teeth of the gastric mill. The smaller part of the cardiac stomach lies between the teeth of the gastric mill and the pyloric valve which is the entrance to the pyloric section of the stomach. When the stomach is filled to maximum capacity in both sections, the ratio of the amount of food in each of the three parts is 6:2:1, respectively (Feniuk, 1945). Each percentage of fullness was assigned a coded index (Table 1). Each part was considered individually and the fullness estimated visually.

TABLE 1. Code for relative fullness of stomachs.

Percentage of fullness	Index (k_x)
Empty	0
Trace of food	1
1–20	2
21–40	3
41–60	4
61–80	5
81–100	6

In order to eliminate variations due to the different sizes of the parts of the stomach, a common index of K_x was obtained for each part by multiplying its index of fullness (k_x) by its factor taken from the ratio of the parts to the whole. The total K factor represents the sum of the K_x factors, i.e., $K=6k_1+2k_2$ ($+1k_3$ not used in these samples). With the entire cardiac stomach filled to maximum capacity, the maximum K obtainable in our samples is 48 units. The percentage of fullness of the stomach, both parts considered, is thus calculated from this K factor. The quantity of food present in the stomachs varied considerably; however, only 7.6 per cent of the stomachs were found to be completely empty. Table 2 shows the distribution of stomach fullness.

TABLE 2. Distribution of stomach fullness in 329 crabs.

Stomach fullness		Number of crabs (in per cent)
Upper limit of K	Equivalent percentage	
0	Empty	7.6
8	Trace	14.4
16	1–20	42.7
24	21–40	18.6
32	41–60	10.0
40	61–80	4.9
48	81–100	2.4

The contents of each stomach were examined microscopically. Although the components occasionally were completely unidentifiable masses of torn tissues; for the most part, relatively large pieces of recognizable materials were present in the anterior part of the cardiac stomach: for example, pelecypod shell fragments, legs and dactyls of crabs, gastropod shell fragments and opercula and legs of brittle stars. Occasionally, complete individuals were found—among these, small brittle stars and amphipods were the most common. Remains in the posterior part of the cardiac stomach were often still recognizable, but were more finely broken from the action of the teeth of the gastric mill. Because no bottom fauna from the sampling area was collected or available for species identification and comparison with organisms present in the stomachs, these organisms, in most cases, were identified only to the class or order level. We express our appreciation to Dr. Paul Illg of the Department of Zoology of

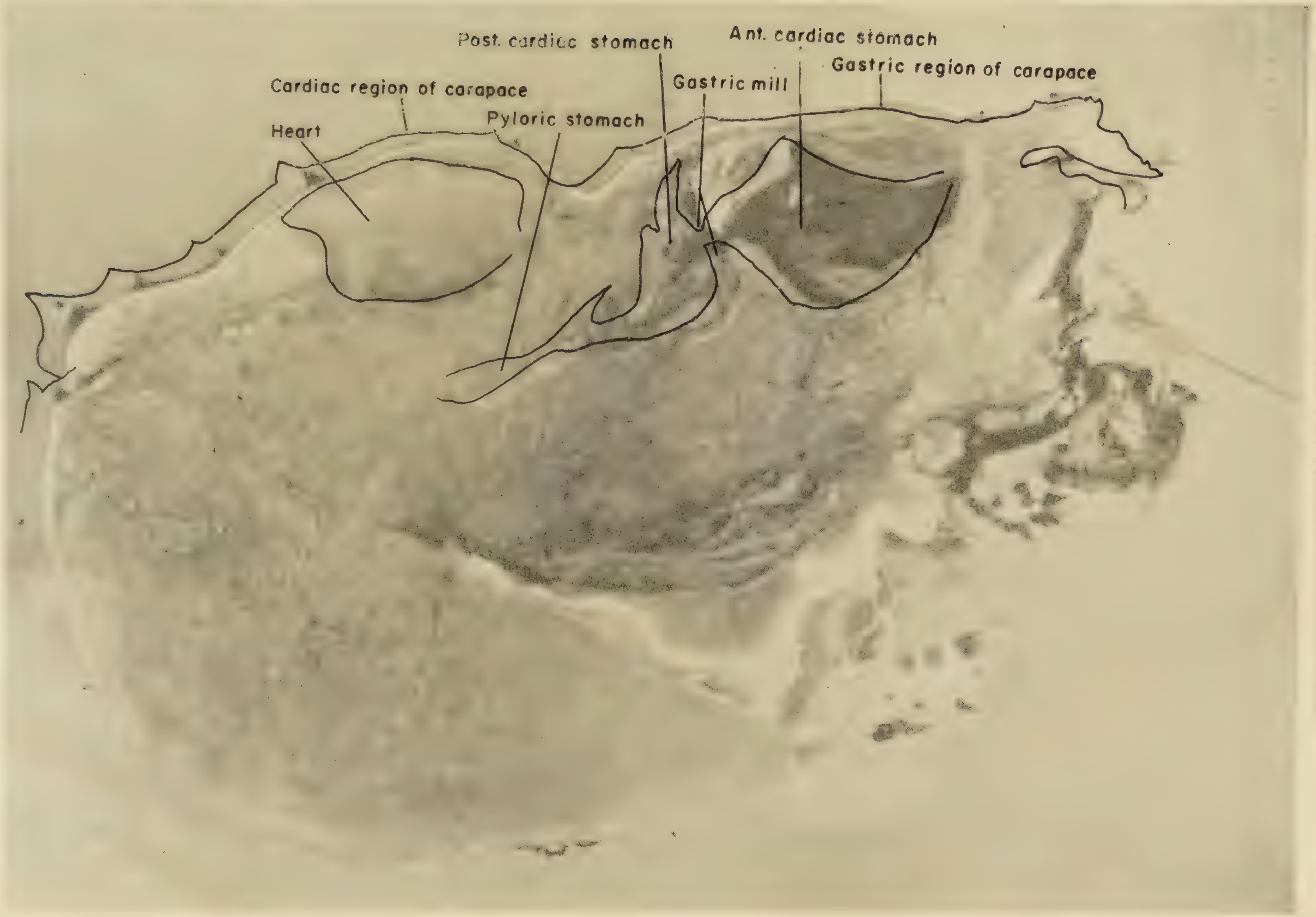

Post. cardiac stomach
Ant. cardiac stomach
Gastric region of carapace
Gastric mill
Cardiac region of carapace
Pyloric stomach
Heart

FIGURE 3. Left side of sagittal section of a king crab.

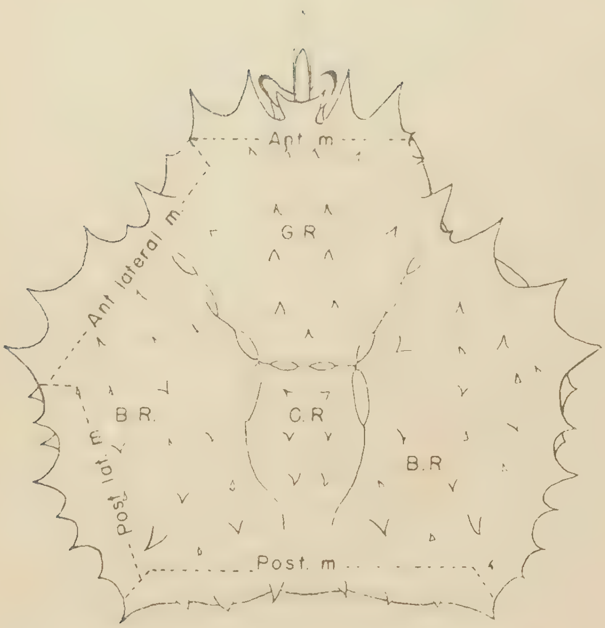


FIGURE 2. Carapace of king crab (after Marukawa).
G.R., Gastric region;
C.R., Cardiac region;
B.R., Branchial region.

farthest from the heart and lies under the region of the carapace defined as the gastric region (Figure 2) by Marukawa (1933). Figure 3 shows the position of the stomach with relation to the carapace and the rest of the body.

The cardiac section of the stomach was dissected out of each crab and preserved in 4 per cent formalin in an individual cloth bag. The pyloric section and the intestine were not used in this study. Anatomically, the cardiac section of the stomach is divided into two parts. The anterior part, which comprises the largest area of the entire stomach, is guarded at its entrance by a hairy filter and at its exit by the teeth of the gastric mill. The smaller part of the cardiac stomach lies between the teeth of the gastric mill and the pyloric valve which is the entrance to the pyloric section of the stomach. When the stomach is filled to maximum capacity in both sections, the ratio of the amount of food in each of the three parts is 6:2:1, respectively (Feniuk, 1945). Each percentage of fullness was assigned a coded index (Table 1). Each part was considered individually and the fullness estimated visually.

TABLE 1. Code for relative fullness of stomachs.

Percentage of fullness	Index (k_x)
Empty	0
Trace of food	1
1-20	2
21-40	3
41-60	4
61-80	5
81-100	6

In order to eliminate variations due to the different sizes of the parts of the stomach, a common index of K_x was obtained for each part by multiplying its index of fullness (k_x) by its factor taken from the ratio of the parts to the whole. The total K factor represents the sum of the K_x factors, i.e., $K = 6k_1 + 2k_2$ $(+1k_3$ not used in these samples). With the entire cardiac stomach filled to maximum capacity, the maximum K obtainable in our samples is 48 units. The percentage of fullness of the stomach, both parts considered, is thus calculated from this K factor. The quantity of food present in the stomachs varied considerably; however, only 7.6 per cent of the stomachs were found to be completely empty. Table 2 shows the distribution of stomach fullness.

TABLE 2. Distribution of stomach fullness in 329 crabs.

Stomach fullness		Number of crabs (in per cent)
Upper limit of K	Equivalent percentage	
0	Empty	7.6
8	Trace	14.4
16	1-20	42.7
24	21-40	18.6
32	41-60	10.0
40	61-80	4.9
48	81-100	2.4

The contents of each stomach were examined microscopically. Although the components occasionally were completely unidentifiable masses of torn tissues; for the most part, relatively large pieces of recognizable materials were present in the anterior part of the cardiac stomach: for example, pelecypod shell fragments, legs and dactyls of crabs, gastropod shell fragments and opercula and legs of brittle stars. Occasionally, complete individuals were found among these, small brittle stars and amphipods were the most common. Remains in the posterior part of the cardiac stomach were often still recognizable, but were more finely broken from the action of the teeth of the gastric mill. Because no bottom fauna from the sampling area was collected or available for species identification and comparison with organisms present in the stomachs, these organisms, in most cases, were identified only to the class or order level. We express our appreciation to Dr. Paul Illg of the Department of Zoology of

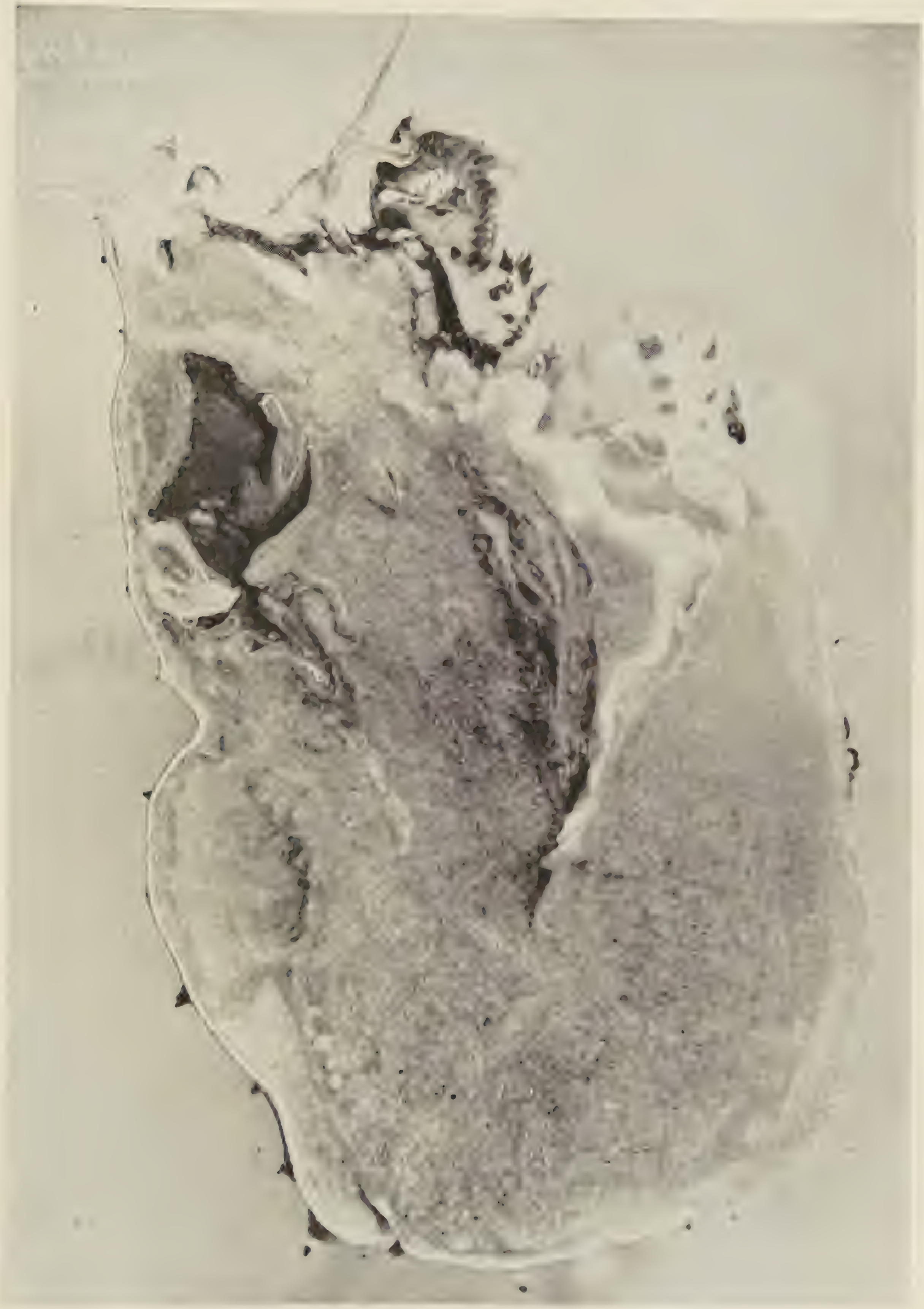


FIGURE 3. Left side of sagittal section of a king crab.

the University of Washington for his verifications of many of our identifications of the food organisms. Remains of organisms which apparently, because of decomposition rather than digestive action, had been dead prior to being ingested by the crabs, as well as the remains of animals which were alive prior to capture, were found in the stomachs.

In addition to the estimation of percentage of fullness, tabulations were made of the frequency of occurrence of the major food groups. In the determination of this frequency, each food group present in a stomach, even when represented by several organisms, was considered to have had an occurrence of one.

Among the food groups represented, molluscs, present in 69.0 per cent of the stomachs examined, are the major food item; pelecypod remains dominating those of gastropods. Echinoderms rank second, appearing in 42.2 per cent of the crabs. Representatives of the phylum include asteroids, ophiuroids, and echinoids of the sub-order Clypeastrina. In contrast to reports in the available literature, no regular echinoids (Hyman, 1955) were present. This lack may be only coincidence, as regular echinoids are most commonly found in rocky areas, and the majority of our samples was not taken from these areas. The third most abundant food group is the decapod crustaceans, which were present in 22.8 per cent of the stomachs, primarily represented by the sub-order Reptantia. Other groups in the order of their abundance include polychaete worms (17.5 per cent), algae (14.3 per cent), crustaceans, excluding decapods, (16.0 per cent), and coelenterates (3.0 per cent). Foraminifera, nematode worms, tunicates, echiuroids, fish and other groups were present occasionally, but not often enough to be considered, on the basis of present information, foods of any relative importance. Possibly these organisms, in some instances, had been carried into the crab stomachs as food of other food organisms.

Contrary to the findings of Feniuk (1945), we found relatively large amounts of algae present in many of the stomachs. At least with regard to king crabs of southeastern Bering Sea, this causes us to question his proposition that algae occur only as a food of other organisms. Sand, which appeared in practically all of his samples, was present only occasionally in our samples, thus leading us to believe that sand may not be a chosen item, but rather one of coincidence. Also, Feniuk's report indicates that the echinoderms play only a minor role in the diet of the king crab of the Kamchatka region, which is in contrast to our data on the southeastern Bering Sea crabs.

Our study, like Feniuk's, shows that the sexes exhibit no food preferences. Table 3 gives the percentages of frequency of occurrence of food groups for males and females.

TABLE 3. Frequency of occurrence of food groups in 169 male and 160 female crabs.

Food group	Percentage of frequency of occurrence	
	Male	Female
Mollusca	76.9	60.6
Echinodermata	48.5	35.6
Decapod crustacea	26.0	19.4
Polychaeta	18.3	16.9
Algae	12.4	16.3
Other crustacea	11.8	15.6
Coelenterata	0.5	5.6

Chi-square tests show no statistically significant differences in the frequency of food group occurrence between the sexes, with the exception of the Coelenterata, and this exception cannot be considered reliable because of the smallness of the sample. Limitations of this preliminary study prohibit further comparison of food preferences, if any, exhibited by newly molted crabs and crabs approaching the molt, or by various size groups of crabs.

SUMMARY

It appears that the major food items of the southeastern Bering Sea king crab, of the sizes studied, are molluscs and echinoderms. On the basis of sex, these crabs do not seem to show a differential preference for particular food items. This preliminary study indicates that a number of differences in feeding habits exist between the southeastern Bering Sea king crab and the king crab of the Kamchatka region. More complete studies are planned to answer the many remaining questions pertaining to the food habits and needs of the king crab.

LITERATURE CITED

FENIUK, V. F. 1945. Analysis of stomach contents of Kamchatka crab. (in Russian.) *Tikhookeanskii nauchno-issledovatel'skii institut rybnogo khoziaistva i okeanografii* (Vladivostok), *Izvestia*, *19*: 71–78.

HYMAN, LIBBIE H. 1955. The invertebrates: Echinodermata. Vol. IV, McGraw-Hill Book Co., 763 pp.

MARUKAWA, H. 1933. Biological and fishery research on Japanese king crab *Paralithodes camtschatica* (Tilesius). *Journal of the Imperial Fisheries Experimental Station* (Tokyo), *4* (Paper 37). 152 pp.

PEARSON, JOSEPH. 1908. L.M.B.C. Memoirs on typical British marine plants and animals. XVI. Cancer. *Liverpool Marine Biology Committee*. London, Williams and Norgate. 209 pp.